THE STABILIZATION OF AEOLIAN SAND DUNES

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DECLARATION

I declare that no material in this thesis has previously been submitted for a degree at this or any other university.

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ABSTRACT

The instability of the surface layer of sand dunes is one of the most important reasons for sand losses through wind and water erosion. This is of particular importance in both the arid environment of Iraq and the coastal dune areas of the UK. In both instances sand dune erosion can threaten farmland, lines of communication etc.

Many attempts have been made to stabilize sand dune systems by means of mulching, fencing, establishment of vegetation cover etc. A key problem with any of these approaches is the difficulty of providing permanent stabilization. Whilst vegetation is the most effective long term agent, it is often difficult to establish such a cover because of erosion and exposure of the root system of the young plants. A possible solution to this is to use a temporary surface mulch which will hold the sand until the plants have become established. The work reported in this thesis examines the utility of a number of chemical mulches for achieving satisfactory stabilization. The chemicals used were a combination of totally new materials - F.E.; Aq1; Aq2; V1 and V3 and materials previously claimed in the literature to be suitable stabilizers - B.E.; PVA1; PVA2; PEG3; PEG4 and V2.

The chemicals were first tested in the laboratory on sand samples collected from the Druridge Bay coastal dune system (Northumberland). Trials were first carried out to determine appropriate application rates of the chemicals so as to achieve a stable but porous surface, this latter is essential since water must be able to penetrate the surface mulch in order to reach the roots of the growing plants. Once the appropriate concentrations had been determined, the effect of the chemicals on: infiltration rate, hydraulic conductivity, sand temperature, evaporation losses and aggregates stability were carried out. Following the laboratory tests a series of greenhouse trials were established in which *Eucalyptus microtheca; Acacia cyanophylla; Ammophila arenaria* and lyme grass tillers, and *Panicum spp.; Merlinda spp.; Melion spp.* and *Ammophila arenaria* seeds were

planted and the sand surface then treated with polyvinyl alcohol 14,000 (PVA1) (0.2% and 0.4%); polyvinyl alcohol 125,000 (PVA2) (0.2% and 0.4%); polyethylene glycol 4000 (PEG3) (0.2% and 0.4%); polyethylene glycol (PEG4) (0.2% and 0.4%); bitumen emulsion A1-55 (B.E.) (0.5 and 1.0 l m^{-2}); Ferquatac emulsion RB-50 (F.E.) (0.2 and 0.4 l m^{-2}); Vinamul 3270 (V1) (0.05 and 0.10 l m^{-2}); Vinamul 3277 (V2) (0.05 and 0.10 l m^{-2}); Vinamul 18207 (V3) (0.05 and 0.10 l m^{-2}); Aquapol 35-0019 (Aq1) (0.33% and 0.66%) and Aquapol 35-0031 (Aq2) (200 and 250 gm m^{-2}). The resistance of the chemicals mulches to wind erosion was tested in a windtunnel. To water erosion it was tested by a rainfall simulator.

The infiltration tests, temperature and seed germination trials were repeated in Iraq using samples from Baiji sand dunes. For these trials the following chemicals were used: Aq1 (0.33%; 0.50% and 0.66%); B.E. (0.3; 0.4; 0.5 and 1.0 l m^{-2}); F.E. (0.14; 0.18; 0.2 and 0.4 l m^{-2}) and PVA2 (0.2% and 0.4%).

From the results of the various laboratory and greenhouse tests F.E.; B.E. and Aq1 were selected for three field trials sites based on a Completely Randomized Block Design at Druridge Bay.

Of the chemicals tested PVA1; PVA2; PEG3; PEG4; V1; V2 and V3 despite comments to the contrary in the literature, i.e. found to be unsatisfactory, largely due to their unstability in water - a vital necessity particularly in arid and semi-arid environments where irrigation may be required in the early stages of the establishment of a satisfactory vegetation cover. The remaining 4 chemicals Aq1; Aq2; B.E. and F.E. were found to be ideal stabilizers, they resisted both wind and water erosion, were none toxic to plants and remained stable for long periods (405 days). The choice of which chemical to use is a combination of aesthetic and cost - Aq1; Aq2 and F.E. are colourless and thus from a public standpoint more acceptable than the black bitumen. However a price has to be paid for this visual/aesthetic appeal since Aq1; Aq2 and F.E. are considerably more expensive than B.E.

A comparison of the infiltration trials on sand from the Druridge Bay system and the Baiji system emphasises the importance of laboratory testing prior to field trials or more widespread use. The maximum chemical concentration that produced a permeable mulch on the Druridge Bay sand was not permeable on the Baiji sand. Thus concentrations quoted in this work must not be applied elsewhere without first conducting laboratory infiltration tests.

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CHAPTER 1

GENERAL INTRODUCTION

The movement of sand and dust by wind occurs in many environments, but is most pronounced and poses the most serious problems for communities, farmlands, factories, roadways, railroads, airports and other installations in arid and semi-arid lands.

In Iraq, for example, desert lands comprise about two thirds of the total ground surface area of 436,000 km^2. The desert includes more than 8 million Iraqi donums of sand dunes (1 Iraqi donum = 2500 m^2), most of which are currently active (Mohammed, 1984). Finding solutions to aeolian sand problems is an important priority for nations which are severly affected by desertification.

Methods of sand dune stabilization take two main directions:

i. techniques aimed at reducing surface wind velocity, for example, the use of the vegetation cover, and

ii. methods of increasing sand particle stability against wind erosion through the increase of sand aggregate diameter, for example, application of soil chemical stabilizers as surface mulches.

Permanent stabilization of the aeolian sand dunes can often be achieved effectively through the development of a vegetation cover. Relative success has been previously achieved with a variety of plants including:-

- *Tamarix articulata*
- *Panicum spp.*
- *Eucalyptus microtheca*
- *Acacia cyanophylla*
- *Artemisia scopari*
- *Tamarix aphylla*
- *Prosopis juliflora*

- *Parkinsonia aculeata*
- *Casuarina conninghamiana*
- *Rizihus communis*
- *Ammophila arenaria* (marram grass)
- *Lolium spp.* (rye grass)

Many attempts to utilize plants in both desert and coastal sand dunes to stop dune movement have failed. In this particular instance failure can be for a variety of reasons ranging from simple water deficiency in the desert to more complex processes such as localised erosion around newly planted vegetation and exposure of the root system in both desert and coastal dunes.

It is important to note that stabilization techniques can be considered to be either short or long term and that, broadly speaking, the former are centred around the application of chemical materials to the sand surface, while the latter depend on the successful planting of different vegetation types. There also seems little doubt that a successful stabilization programme will rely on a careful combination of both sets of techniques.

This study was designed to investigate the suitability of two techniques available for stabilizing sands in both coastal and arid environments, namely the use of vegetation and the use of mulches involving various chemical stabilizers. The experimental design involved both laboratory and field studies. Before adopting any chemical mulches for field trials, a series of the laboratory and greenhouse tests were performed on the mulches, in which infiltration and conductivity rates; toxicity effects; effects on temperature, evaporation and sand aggregation (both dry and wet) and stability against both wind and water erosion were determined.

The use of these initial laboratory and greenhouse trials enabled only the most successful mulches to be selected for field trials. Thus of the initial 11 mulches used at the outset only three were carried forward for field trials at Druridge Bay. Here three sites were selected and set out in a Completly Randomized Block

Design with three blocks at each site.

The three mulches adopted for field trials at Druridge Bay, were also tested for their effects on germination rates; sand temperature; infiltration rate and the hydraulic conductivity under laboratory and greenhouse conditions on dune sands in central Iraq.

Chemical mulching is a very good method for the stabiliztion of the surface layer of sand dunes, especially when a large area needs to be stabilized in a short period (Zoght, 1978). Where vegetation is ultimately to stabilize the surface, the chemicals must not restrict plant growth by toxic effects or prevent water penetration. In general, the use of any chemical material depends on the following:-

1. High level of the adhesive force.
2. High Permeability.
3. Ease of mixing in, and reaction with water.
4. Non toxic to plants.
5. Remains stable for prolonged period.
6. Cost-effectiveness: this will vary with need for stabilization.
7. Environmentally friendly, i.e. non toxic and ideally invisible/colourless.
8. Need for stabilization.

In this study of sand dune stabilization, the following chemicals were used:

- Polyvinyl alcohol 14,000
- Polyvinyl alcohol 125,000
- Polyethylene glycol 4,000
- Polyethylene glycol 400
- Vinamul 3270
- Vinamul 3277
- Vinamul 18207
- Ferquatac emulsion RB-50
- Bitumen emulsion A1-55

- Aquapol 35-0019
- Aquapol 35-0031

Work within this study was concentrated particularly on: (i) effect of the above mentioned chemical materials on the sand physical properties; (ii) effect of the chemical materials on reducing sand erosion; and (iii) the ease with which the plant species can penetrate the chemical stabilizers and also how successfully young plants can survive. A continuous chemical film over the ground surface may, for example, act as a barrier against the movement of gas molecules through the soil surface, hence restricting plant growth. Specific plants including: *Panicum spp.; Eucalyptus microtheca; Acacia cyanophylla; Ammophila arenaria* (marram grass); *Lolium spp. (Merlinda spp.* and *Melion spp.);* and lyme grass had been chosen with the following points in mind:

i. Compatibility with the regional ecology.

ii. Speed of growth.

iii. Cost effectiveness.

iv. Suitability as a grazing material once established.

v. Susceptibility to drought conditions.

In order to achieve the three main objectives of this study, the following laboratory, greenhouse and field investigations were performed:-

1. Effect of selected chemical stabilizers on soil physical properties, including:-

a. Effect of soil chemical stabilizers on the movement of water into and through soils.

b. Effect of soil chemical stabilizers on the soil temperature.

c. Effect of soil chemical stabilizers on soil water evaporation.

d. Effect of soil chemical stabilizers on soil aggregate formation (wet and dry Aggregates).

2. Effect of soil chemical stabilizers on seed germination, including marram grass; *Merlinda spp.; Melion spp.* and *Panicum spp.* (both on Druridge Bay

and Baiji sand dunes).

3. Effect of soil chemical stabilizers on plant growth, including marram grass; lyme grass; *Eucalyptus spp.* and *Acacia spp.*
4. Effect of soil chemical stabilizers on soil erosion by wind and water.
5. Field work studies:

These included the effect of the combination between the selected chemicals and the growth of both marram grass and lyme grass plants on:-

a. Plots side erosion.
b. Plots sand erosion and sand accumulation.
c. Water infiltration rates.
d. The modulus of rupture.

In the remainder of the thesis chapter 2 presents a general review of the dynamics of wind blown sand. This sets the scene for chapter 3 which contains broad survey of the available literature on the methodology of sand dune stabilization. The choice of chemical stabilizers, sand subtrates and plant species used in the various trials are discussed in chapter 4. In chapter 5 the results of the laboratory and greenhouse trials on Druridge Bay sands are considered; whilst, in chapter 6 the laboratory and greenhouse trials using Iraqi sand are discussed. The effect of laboratory erosion experiments are discussed in chapter 7, prior to the analysis of the field trial experiments at Druridge Bay in chapter 8. The final conclusions and recommendations of the study are presented in chapter 9.

CHAPTER 2

DYNAMICS OF WIND BLOWN SAND - GENERAL REVIEW

2.1 Definition of Sand Dunes

The research of many geomorphologist in the second half of this century has concentrated on sand dunes as a desertification phenomenon (Shaker, 1985). Longwell et al. (1948); Bagnold (1954); Holm (1968); Glenn (1979); Hasan et al. (1982); and Shaker (1985) all agree that a sand dune is a topographical feature of aeolian origin consisting of sand* grains derived from natural sources.

"A dune is any accumulation of wind blown material with sand size particles or less. While, sand dunes mean, a ridge or pile of sand resulting from aeolian action" (Stone, 1967).

Mobile sand dunes are heaps of moving sand, of different sizes. They occupy large areas in many parts of the world and are generally areas of zero productivity, often threatening to cover inhabited localities e.g. roads, farms, water channels and other resources (Zoght, 1978).

Mainguet (1984) defined the dune as "an accumulation of loose particles, deposited or reworked by the wind, with diameters varying from 2 mm to tens of micrometres". He argued, that the accumulations of loose particles deposited or reworked in fluvial environments (in seas, lakes, or river streams) cannot be considered as dunes because of the absence of sharp crests.

2.2 Classification of Sand Dunes

Many studies have attempted to classify and explain the formation of sand dunes and other aeolian deposits. Most of these classifications are topological, depending on the form and disposition of dunes (Aufrere, 1933; Smith, 1954; Foujita, 1967; Holm, 1968; Cooke and Warren, 1973; Mainguet, 1976; and Walker and

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* *Sand is soil particles of 0.05 - 2.00 mm in diameters (Richards, 1969).*

Middleton, 1977). Aufrere (1931a), however, proposed a dynamic classification of dunes, depending on wind direction. Al-Sanawi et al. (1979) followed this latter approach, classifying active sand dunes into the following categories according to dominant wind regimes:-

1. Transverse dunes, due to monodirectional wind. They are oriented perpendicular to the prevailing wind direction.
2. Longitudinal dunes, due to the wind being continually disrupted by topographic irregularities or bidirectional winds. They are oriented parallel to the prevailing wind direction.
3. Parabolic dunes, due to monodirectional wind direction. They are U-shaped dunes pointing downwind.
4. Star dunes, due to non dominant wind direction.

Hack (1941) related the above mentioned dune types to the wind strength, sand supply, and amount of vegetation.

Mainguet (1984) argued that, although the above mentioned classification was used by many authors (Bourcart, 1928; Aufrere, 1931a; 1931b; and Fryberger, 1979), it is not enough to classify dunes based only on their dynamics. It is necessary also to consider two other fundamental parameters, the budget of sand and the directions of accumulation and exportation. Thus, the classification of sand dunes by Mainguet (1984), is based on proposed dynamic criteria, through the differentiation between the topological form, the direction of winds, and the sand budget as a function of time. Thus in a region where the importation of sand is more than sand exportation, active sandy edifices are formed called depositional dunes. These include barchanic edifices, linear dunes, and star dunes. Erosional dunes, including parabolic edifices, and sandridges are formed when sand exportation exceeds its importation.

Breed and Grow (1979) provided a comprehensive review of the literature on dune types and their distribution.

Although Mckee's (1979) dune (and other sand deposits) classification scheme is based on Hack's (1941) dune types, it differs from other previous studies in two important ways. Firstly, it incorporates the knowledge gained from the analysis of the internal structures of dunes, and secondly, by using Landsat images it enabled a world wide analysis of dunes to be made. Greeley and Iversen (1985) further modified the schemes of Mckee (1979) and Breed and Grow (1979) to produce the schemes given in table (2.1) and figure (2.1). The dunes in table (2.1) are essentially simple dunes (single dunes and dune types); compound dunes (two or more dunes of the same type overlapped or combined with each other); and complex dunes (more than one type of dune overlaped or combined to each other).

An added complication to the classification of dunes is the fact that there is a proliferation of local names for the same feature. For example, in Wahiba sand dunes in Oman (Warren, 1986) found that it contains a quite extra-ordinary variety of dune names. Large and small ridges, barchans, mega-barchans, fuljs[1], active transverse dunes of various sizes, oblique dunes[2], zibar dunes[3], sayf[4] and

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[1] *Fulji or Fulje: Depression between barchan dunes having a steep slope on the windward side and gentle slope on the lee side (Stone, 1967). Lee is shelter or the part of side sheltered or turned away from the wind.*

[2] *Oblique Dunes: Dunes oblique to the dominant wind direction.*

[3] *Zibar Dunes: Rolling transverse dune ridge of low relief without vegetation cover, or a slip face that is formed between dune complexes and especially in low areas between linear dune belts (Stone, 1967).*

[4] *Sayf or Seif: is the Arabic name for the sword. It is a variety of longitudinal dune or long dune chain oriented in the direction of wind movement (Stone, 1967). Individual dunes may be as much as 60 miles long and 700 ft. high and chains in Egypt are 200 miles long. Term originated in North Africa but is applied in North America to similar dunes of appreciably smaller size.*

Table 2.1: Basic Dune Types (Modified from McKee, 1979a; Cited by Greeley and Iversen, 1985).

Name	Form	Slipface(s)	Wind[a]
Transverse			
- Barchan	Crescent in plan-view	1	Transverse
- Barchanoid ridge	Rows of connected crescents in plan-view	1	Transverse
- Transverse ridge	Asymmetric ridge in cross-section	1	Transverse
Longitudinal	Symmetric ridge in cross-section	2	Parallel
Parabolic	U-shaped in plan-view	1 or more	Parallel
Dome	Circular or elliptical mound	none, or poorly defined	.....
Star	Central peak with three or more arms	3 or more	Multiple

[a] Refers to orientation of dune axis with respect to wind direction or the vector of more than one wind direction.

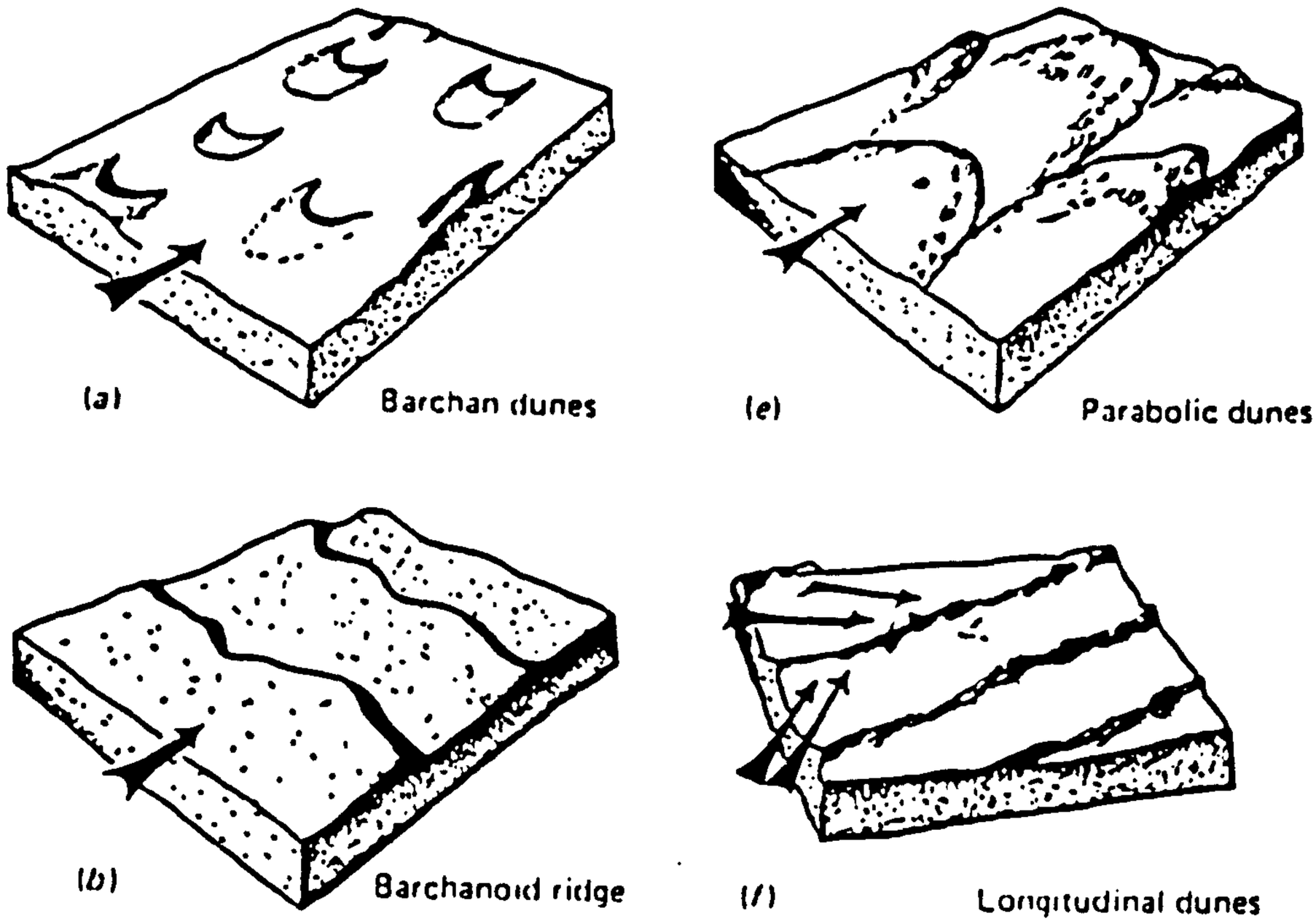
nabkah[5] dunes.

2.3 The Formation of Sand Dunes

The activity of man and his animals, the unwise management of crop lands, excessive cutting of tree and forest cover, overgrazing of rangelands, and ecological factors all play an important role in the balance of the soil environment in arid environments (Zoght, 1978). Thus desertic sand dune formation can be seen to be

[5] *Nabkah: is a North African term for dunes accumulating around bushes (Cooke and Warren, 1973 p 107).*

Figure 2.1: Diagrams Illustrating the Principal Dune Types and the Winds Responsible for Their Formation. (From McKee, 1979; Cited by Greeley and Iversen, 1985).



a combination of ecological forces and the improper management of the natural resources, especially soil and water (Al-Taie, 1984; and Tunisian Report, 1984). This interaction is exemplified in the origin of sand dunes in the County of Salah Al-Deen (Baiji and Al-Aith regions), Al-Massab Al-Aam and other Iraqi sand dunes regions (Mohammed, 1984). More information about the formation of Iraqi sand dunes will be discussed in chapter six.

Coastal dunes on the other hand, usually develop in areas of low lying coastal land adjacent to large sandy beaches, with on shore winds being responsible for the accumulation of sand. The dunes can be destabilized by similar poor management practices experienced in desertic environments, eg. clearing, cultivation, overgrazing by stock and increasingly concentrated recreational activity eg. children sliding down soft faces (Mitchell, 1974; and Greeley and Iversen, 1985).

2.4 Processes of Sand and Dust Transportation by Wind

Much of the early research on the basic physics of wind blown sand (grain sizes from 0.05 to 2.0 mm diameter); and dust (grain size diameters less than 0.05 mm). This pioneering work was carried out primarily in Egypt, Great Britain and U.S.A. by Bagnold (1941) and Chepil (Chepil, 1949; 1957; and Chepil et al., 1952).

Three steps are involved in the mobilisation and movement of sand by wind (De Boodt and De Vleeschauwer, 1981):-

1. The initiation of the particles movement.
2. The transport of the aeolian material.
3. The sedimentation of the aeolian material.

The detailed mechanics of sand and dust movement are reviewed by Bagnold (1954); Chepil and Woodruff (1963); Rostler and Kunkel JR. (1964); Cooke and Warren (1973); Mabbutt (1977); Watson (1985); and Greeley and Iversen (1985). They all agreed that there are three types of sand and dust transportation by

wind:

Suspension, (mostly clay and silt particles, i.e., smaller than about 0.05 mm), which occurs when the turbulent component of the wind velocity is greater than the final fall velocity of the grains. This accounts for about 5% of the total sediment movement in dune sand.

Saltation, (mostly sand-size particles 0.05 - 2.0 mm in diameter), which accounts for about 72% of particle movement.

Traction and Surface Creep, (> 2.0 mm in diameter), which involves the rolling, sliding and pushing of particles along the ground surface. It accounts for the remaining 23% of movement.

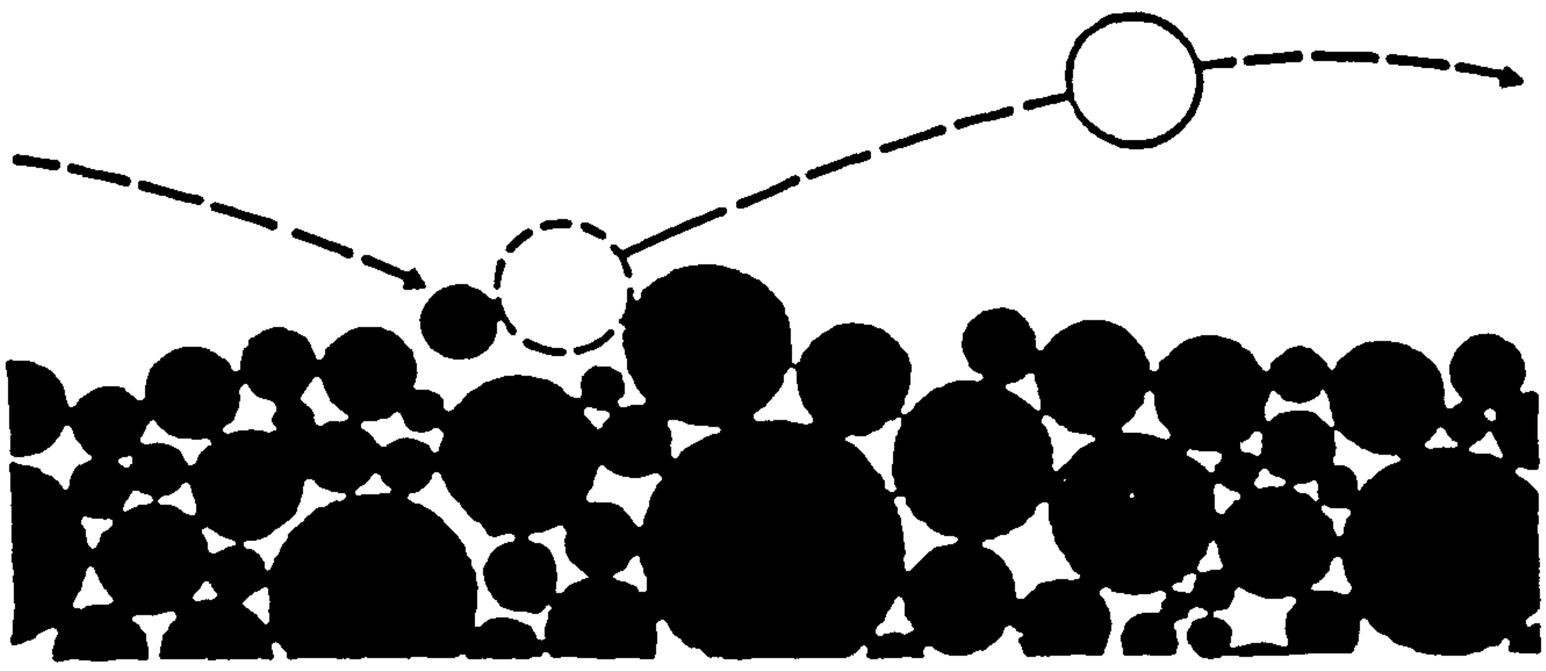
It is obvious that, wind velocity and air turbulence directly affect the entrainment and transport of sediment by providing the necessary energy to transport the grains in creep, saltation, and suspension (Nickling, 1978).

These three processes are not independent of each other, and always occur simultaneously. They are much like the motion of "elastic balls" on impact (Rostler and Kunkel JR., 1964). Saltation is largely responsible for surface creep and for suspension. These processes are illustrated in figure (2.2).

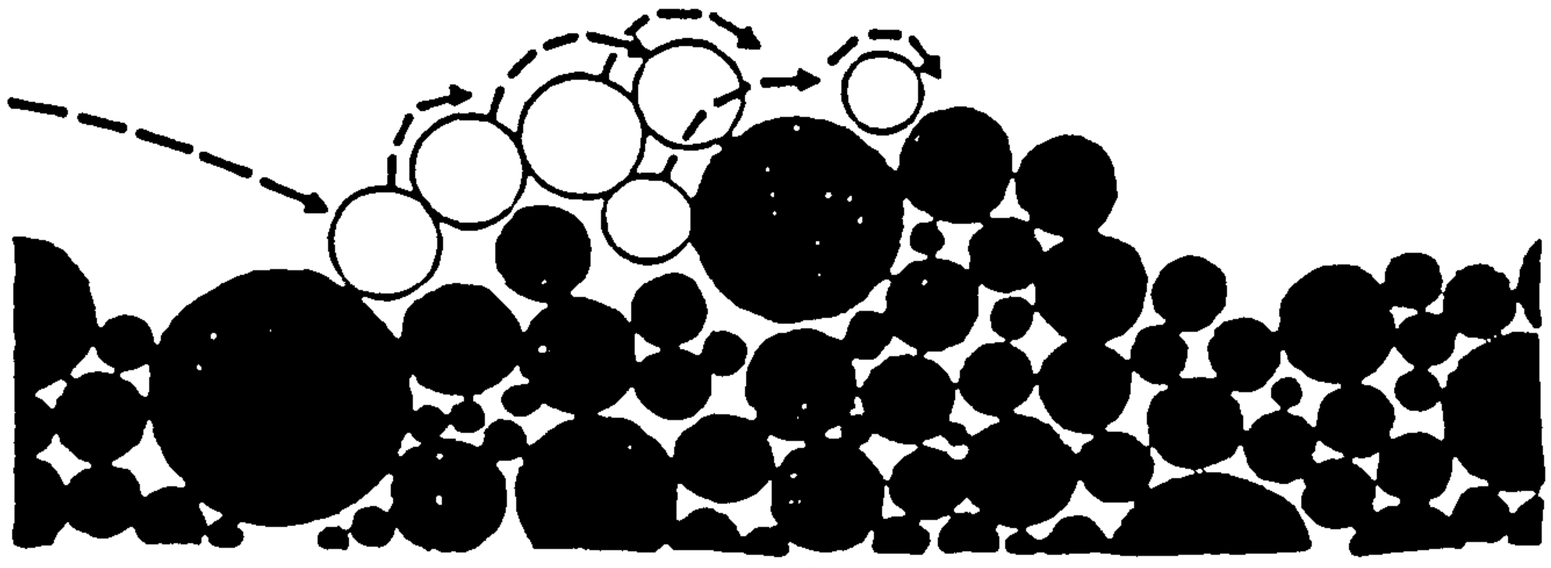
It is important to understand the mechanism of soil particle erosion so that appropriate techniques can be applied to prevent this. De Boodt and De Vleeschauwer (1981) indicated that, the sensitivity of soil towards wind erosion varies as a function of air-current (air speed, turbulence and density), condition of the soil surface and soil structure stability. Pasak (1974) for example, considered that soil aggegates > 0.8 mm in diameter are sufficiently stable against wind erosion. However, wind and water erosion, are more effective in soils or sand dune fields with individual particles than with large aggregated ones. Therefore, chemical stabilizers, for example, could be used as surface stabilizers for the soil in order to create sufficiently stable aggregated units so as to withstand wind and water erosion (Armstrong and Chesters, 1964; and Vandevelde and De Boodt,

Figure 2.2: Modes of Soil Transport

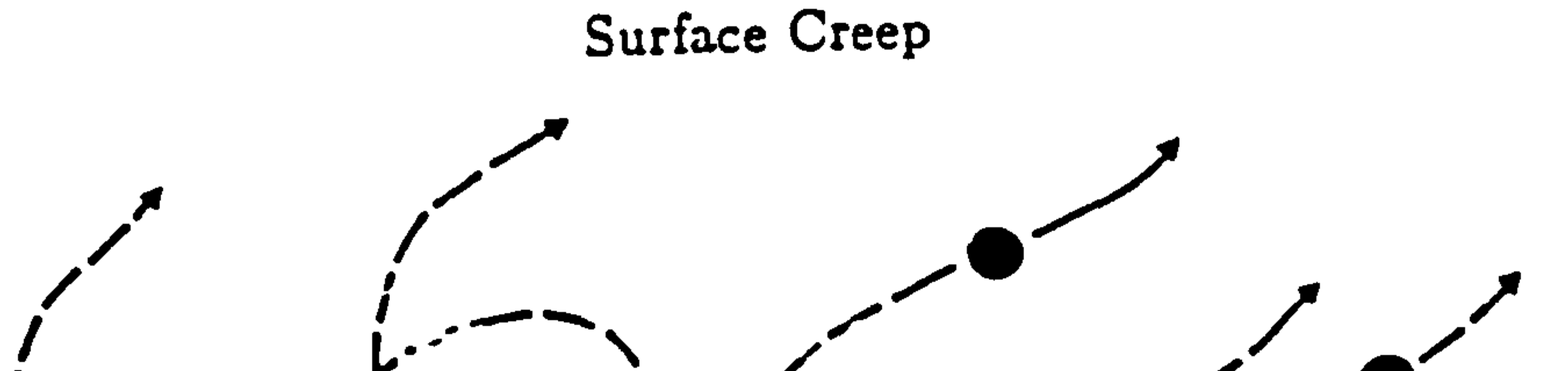
(From Rostler and Kunkel JR., 1964).



Saltation



Surface Creep



Suspension

1972).

2.5 Problems of Sand Dune Movement

Creeping dune sands in most countries especially those that are suffering from dryness and desertification are considered an ecological and economic problem, which no method can completely solve. Photos (2.1 - 2.4) show some of these problems. Greeley and Iversen (1985), identified three distinct groups of problems including, environmental, agricultural, and transportation. Environmental problems have to do with the effects of dust on health, visibility, and climate, as well as on engineering considerations such as abrasion by wind blown grains. Agricultural problems involve loss of soil, sand, plants and fertilizers. The effects on transportation include the protection from, or removal of, blown sand on highways, railroads, and airport runways etc.. Cooke et al. (1985), provided a very good review about the problems of sand and dust movement. They classified these problems into three fundamental aeolian processes: deflation, transport, and deposition.

It is obvious that the drifting of sand in some places is very severe. For example, in the Eastern Province of Saudi Arabia drift rates of wind blown dunes sand reach 30 m^3 m^{-1} width annually, and barchan dunes, up to 25 m in height, have an average rate of movement of nearly 15 m per year (Watson, 1985). World wide, the annual problems and damage arising from sand movement are considerable. For example, the Nairobi Conference (1977), estimated the total yearly cost of damage to agricultural lands, irrigation and drainage channels, and civilian and industrial installations due to drifting sand dunes was c$10 billions (ACSAD, 1984).

Plate 2.1: Movement of Sand Dunes Towards a Date Farm (Tunisia).

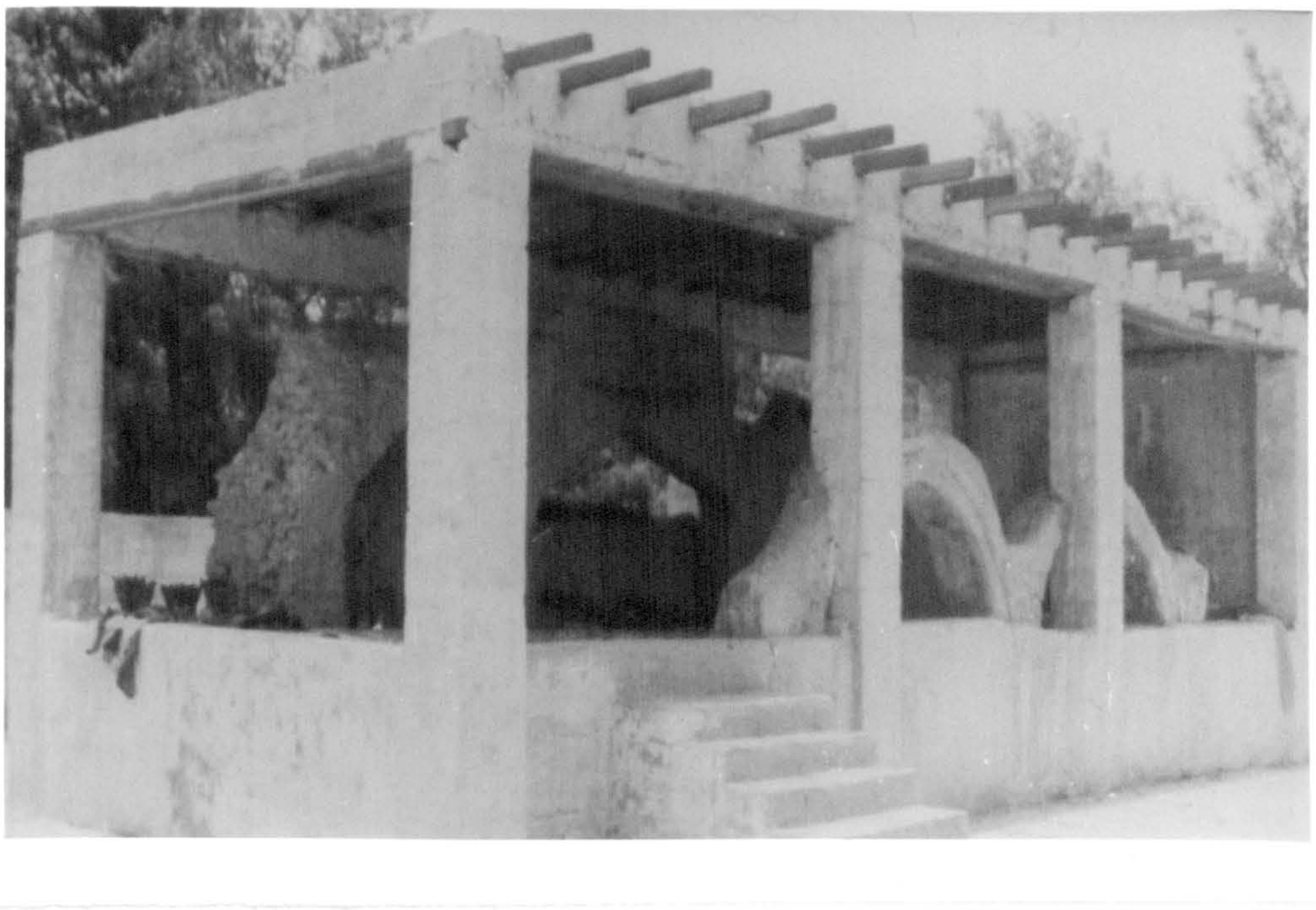


Plate 2.2: An Old Mosque in Saudi Arabia Recently Rediscovered After Being Buried by Mobile Sand Dunes for Hundreds of Years.

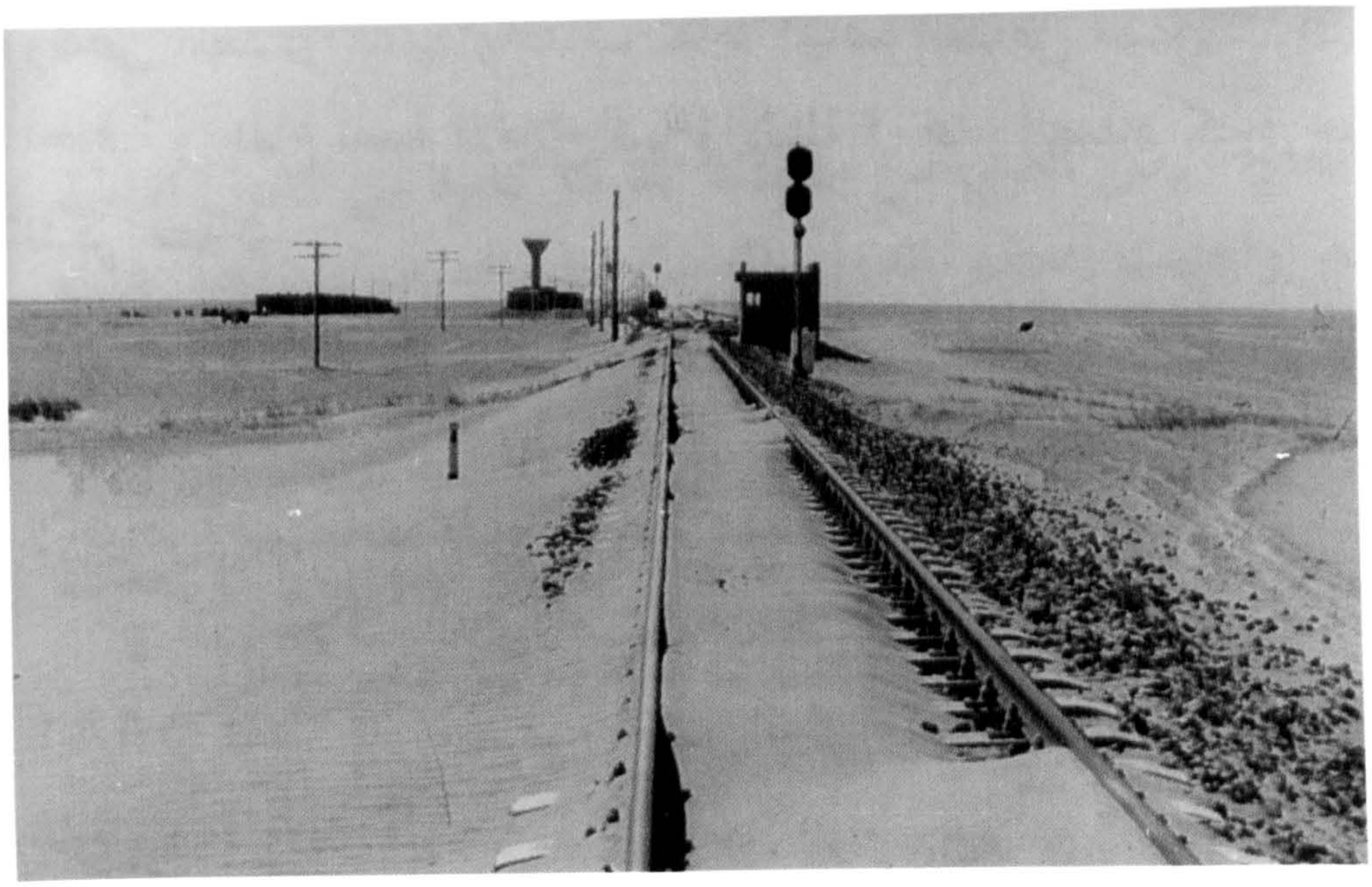


Plate 2.3: Movement of Sand Dunes Across a Railway Line in Syria.

Plate 2.4: Movement of Sand Dunes Causing Disruption of an Irrigation Canal in Syria.

CHAPTER 3

REVIEW OF STABILIZATION

3.1 Methods of Aeolian Sand Dune Stabilization and Control

Professional engineers and agriculturalists have taken an interest in dune control only in the last four decades and much of their research and development have taken place in the Arabian Peninsula (Warren and Kay, 1986). Many countries and some large companies support or have supported dune-fixing specialists and programmes. Most of this experience was summarized in a very good review by (Watson, 1985).

The control of wind blown material, whether sand or dust, is a worldwide problem, for which solutions have been sought in both laboratory and field test research (Jensen, 1976; Ring et al., 1979; Iversen and Jensen, 1981; Al-Masoodi, 1984; and Tunisian Report, 1984).

Methods of sand dune stabilization can be grouped in several ways:

a) Knottnerus (1976) argued for scheme based on a separation of methods that can decrease the wind velocity at the surface and those that can reduce the erodibility of the sand itself.

b) Shakhatreh (1985) suggested a system based on the length of time that dunes had been stabilized.

Kerr and Nigra (1952), Zoght (1978), Mainguet (1984), Cooke et al. (1985) and Watson (1985) argue in favour of a scheme based on the methods used in stabilizing the dunes: (i) avoidance, removal, or control; (ii) fencing and palisading; (iii) surface stabilization; and (iv) vegetation.

Regardless of how stabilization is approached or methods classified, Shakhatreh and Authman (1984) and Shakhatreh (1985) demonstrated that methods of sand dune stabilization rest on two principles:

i. Mechanical fixation: This aims to reduce the velocity of the wind to make it lose it's ability to erode; and/or prevent wind reaching the sand surface.

ii. Biological fixation: This type of fixation aims to stabilize and fix sand dunes; improve the local environmental conditions and to convert sand dunes into productive lands.

Following the approach of Kerr and Nigra; Mainguet; Zoght; Cooke et al. and Watson, the techniques that can be used in stabilizing sand dunes will be reviewed in further detail under the four headings: (1) Avoidance, Removal, or Control; (2) Fencing and Palisading; (3) Surface Stabilization; and (4) Vegetation.

3.1.1 Avoidance, Removal or Control

In sand dune environmental management, avoidance of hazard areas and surface disturbance is often more effective and cheaper than control both in the short and the long term (Cooke et al., 1985). In certain circumstances where only small dune systems are involved complete removal by earthmoving equipment might be a practical, but expensive solution. Where sand is continuously causing problems by advancing across roads, railways, etc, clearance, despite its cost, is obviously necessary. However, it is only a temporary measure.

Both Cooke et al. (1985) and Watson (1985) agree, that the only practical method of dune removal is mechanical excavation and transportation to a new location. The costs are high since a 6.0 m high dune may incorporate 20000 - 25000 m^3 of sand weighing between 30000 and 45000 tonnes depending on the volumetric porosity of the material (Watson, 1985).

Finally, it could be concluded, that the solution of removing the sand or dissipation of the dunes is practical only in areas when the sand could be utilized as fill or ballast (Watson, 1985), or where drifting sand does not pose a big hazard. Thus if avoidance and removal are impracticable, control measures are required, examples of these are reviewed in the following sections.

3.1.2 Fencing and Palisading

The effectiveness of any fence depends on the relations between wind speed, total sheltered area, and fluid threshold speeds (Cooke et al., 1985). Cooke et al. (1985) mentioned that, semi-permeable forms of fences are more effective in sand dune stabilization than impermeable ones, owing to the greater turbulence caused by the latter. The number of fence rows and their heights are two other practical factors that need to be considered. Manohar and Bruun (1970), found that the optimum number of fence rows is about four, if more fences are installed, the added sand trapping effect is negligible. Double row fences trapped sand at velocities higher than 58 kph, at which velocity a single row fence ceases to be effective.

Greeley and Iversen (1985) indicated that, in arid and semi-arid zones, where plant material was used as fencing, only dead plant material should be used, thus avoiding later competition with the trees (where forestation is the objective). Palm fronds fences (and fences of other dead plants including *Salsda bestifer; Phragmitis cummunis; Artemisia spp.; Imperata cylindrica; Aristida pungens;* and *Retama retam*) are still used to control sand dunes in the Middle East and North Africa (Abdul-Wahed, 1982; Hannah, 1984; Al-Masoodi, 1984; and Warren and Kay, 1986). Palm fronds are usually divided into 120 cm sections which are then fixed vertically in the sand for 20 - 30 cm in parallel straight lines perpendicular to the wind direction. The distance between one line and another is usually between 3 and 5 m. Hannah (1984) demonstrated that although providing good dune stabilization in Iraq, this method was expensive.

3.1.3 Surface Stabilization

This method includes, the stabilization of sand dunes with one or more of the follwing materials:

(i) Water: The characteristics of sand moisture content is a poorly understood

topic. The water-holding properties of dune sand itself has an additional importance as it affects plant growth and so it controls the dune form (Warren and Kay, 1986). Water is only a good stabilizer if the surface is kept wet - it is more difficult for the wind to pick up wet sand than dry sand. Hyde and Wasson (1983) showed that a thin layer of wet sand just beneath the surface of an Australian semi-arid sand dune, controlled the rate at which sand was removed from a dune slope.

The effect of moisture on the threshold speed of sand has been investigated both in the field and in the wind tunnel (Belly, 1964; and Svasek and Terwindt, 1974). Svasek and Terwindt (1974) showed that, while sand containing about 0.8% water (by volume) does not move until the shear stress velocity is about 0.65 m sec^{-1}, dry sand is moved by the wind when the shear stress velocity is greater just than 0.17 m sec^{-1}. The difference suggests that the wind speed of only 5.0 m sec^{-1} at about 2.0 m above the sand surface is able to move dry sand, whilst it must be about 15 - 20 m sec^{-1} to move damp sand.

Finally, it is important to mention that, continual application of large quantities of water would be required to maintain the stabilization of sand dunes, especially in arid and semi-arid zones, in which strong winds are prevalent and the sand surface temperatures in the summer months could reach $70^{o}C$ (Watson, 1985). Such wasteful use of water is not acceptable in such locations.

(ii) Gravel, stones, crushed rock and clayey soils: In natural sand deserts a surface lag of coarse-grained materials (e.g. gravel and stones) often acts as an effective protection against erosion of sand from the surface (Chepil et al., 1963c; Cooke et al., 1985; and Watson, 1985). In some circumstances an artificial lag can be formed using crushed stone, a minimum grain diameter of about 20 mm is required, since smaller particles will be affected by surface creep (Watson, 1985). The layer of lag materials should not be less than 50 mm thick, since if it is disrupted, rapid scouring of the underlying sediments will occur (Logie, 1981).

Although a successful solution, the actual spreading of these materials over

unstable sand surfaces poses a number of problems. Furthermore, when the Cost of transportation of these bulky materials taken into account, then the practical use of this technique for sand dune stabilization is extremely limited.

A layer of clayey soil can also be used for the protection of the surface of the aeolian sand dunes from deflation. In Iraq, for example, a 10 - 30 cm layer of clayey soil (35% - 50% clay; 36% - 51% silt and 5% - 28% sand) was found to be successful for the protection of Al-Numania sand dunes (65% - 94% sand; 0% - 18% silt and 6% - 17% clay) against wind erosion (Hannah, 1984).

(iii) Oil and chemical materials: Much work has been carried out with crude oil; oil extracts; emulsions and synthetic organic polymers, in attempts to elucidate the interactions between them and both organic and inorganic soil materials (Saleh, 1984). Watson (1985) indicated that, chemicals either form a protective coating over the surface or create cohesion between the surface particles. Chemical mulching is a very good method for the stabilization of the surface layer of sand dunes, especially when a large area needs to be stabilized in a short period (Zoght, 1978). Where vegetation is to ultimately stabilize the surface, the chemicals must not restrict plant growth by toxic effects, prevent air and water penetration or seedling emergence. Data on the environmental consequences of these stabilization techniques are non-existant. The effect of the chemical materials on plant life, and their susceptibility to leaching or erosion by rainwater must also be taken into account (Gabriels et al., 1974; and Polyakova, 1976).

Sand dune stabilizing materials have been developed from latex, asphalt-type materials and other oil products and commercial chemical materials which are diluted with water and sprayed on the sands (Greeley and Iversen, 1985). Three types of oil extract are commonly used (Kerr and Nigra, 1952; FAO / DANIDA, 1974; and Cooke et al., 1985):

1. Low-gravity asphaltic oil
2. High-gravity deep-penetrating waxy oil

3. Crude oil

Chemical sprays other than oils require specialized equipment and trained personnel. The amount of the chemicals used depends on soil structure, slope, spraying technique and the degree of stabilization required (Cooke et al., 1985). Whether chemical mulches are economical or not depends on the costs of these products in a given region in comparison with the savings in labour costs, and why stabilization is needed.

De Boodt (1975) argued that because the soil conditioners and synthetic chemical stabilizers can be used in liquid form, and the technology developed for spraying pesticides can be adopted with little difficulty for applying soil conditioners, considerable saving can be made on costs. Various attempts have been made to cut the costs of oil extracts and chemical substances by spraying limited areas, such as only the windward slope of transverse dunes, or 2 m strips separated by 4 m of bare sand (Warren and Kay, 1986).

Chemical materials are of two main types (De Boodt, 1979; Hannah, 1984):

1. Hydrophobic chemicals which dissolve easily in water, and include:

- Polyvinyl alcohol (PVA)
- Polyvinyl alcohol urethanised (PVAU)
- Sodium polyacrylate (SPA)
- Polyacrylamide (PAM)
- Partially hydrolised polyacrylonitrile (HPAN)

2. Hydrophilic chemicals which do not dissolve completely in water, and include:

- Polyvinyl acetate (PVAc)
- Polyurethane (PU)
- Potassium polystyrene sulphonate (PS)
- Vinylacetate meleic acid co-polymer (VAMA)
- Polybutadiene (PBUT)

- Polysiloxane
- Natural rubber latex
- Asphalt (bitumen)

In general, the use of any chemical material depends on the level of the adhesive force which is required, the permeability of the sand, the reaction of the chemical with water, the toxic effects on plants, the environmental susceptibility and acceptibility, the cost-effectiveness of the chemical and the need for stabilization.

Combined with the seeding of grasses, chemical mulching has given excellent results in some areas (Greeley and Iversen, 1985). It is essential in these circumistances that the synthetic dune stabilizers remain functional until the growing vegetation can take over the erosion protection/stabilization function.

Oil and chemical stabilizers have been used in many countries including Libya, Morocco, Australia and South West Africa (Leroux, 1974; Mitchell, 1974; and Al-Masoodi, 1984). A report from ACSAD (1984) discussed the uses of chemical soil conditioners, and gave a list of chemical substances which have been used as sand dune stabilizers in many places; the chemicals included:

- Oil materials
- Polyvinyl acetate (PVAc)
- Polyacrylamide (PAM)
- Supergel
- Hydrogel (RAPG)
- Agrosok and some other chemical substances

These chemicals were produced by companies in Belgium; Egypt and the United Kingdom.

More information about the role and the mechanism of chemical soil conditioners on soil aggregates formation will be illustrated later within this chapter.

3.1.4 Vegetation Stabilization

Permanent or semi-permanent sand dune fixation requires the stablishment of permanent plant cover capable of preventing the sand surface from wind erosion. There are numerous plant species which can act as natural sand dune stabilizers. The species colonising sand dunes vary with the nature of sands, climatic conditions, land use and moisture content of sands (Zoght, 1978). On deep sands (10 - 15 cm deep), the following bushes and grasses with deep roots are commonly found:

- *Haloxylon spp.*
- *Calligonum spp.*
- *Anabasis spp.*
- *Panicum spp.*
- *Retama raetam*

While on very deep sites (often > 35 m deep), where succession takes place, tree species dominate eg:-

- *Acacia spp.*
- *Prosopis spp.*
- *Lycium arabicum*
- *Leptadenia perotechnica*
- *Salvadora spp.*
- *Zizyphus spp.*

On salty sands a much restricted range of species is found eg:-

- *Tamarix spp.*
- *Vernonia spp.*
- *Suaeda fruticosa*
- *Aeluropis repens*

A similarly limited range of species is found on eroded sites eg:-

- *Zygophyllum spp.*

- *Calatropis procera*

- *Cyperus spp.*

Marram grass, rye grass and lyme grass are the most common plants on coastal sand dunes.

Where tree planting takes place in desertic environments, Zoght (1978) suggested that, the following conditions should be observed:-

1. Planting should be deep enough to reach the moisture content of deeper sand layer (over 50 cm).
2. Quality of plants should be good, in particular the size and extent of the root system must be suitable for deep planting.
3. Cuttings should be long enough (over one metre) for deep planting.
4. Time of planting should be set after the sands receive enough moisture (over 50 mm of rainfall).
5. Species chosen should be appropriate for the prevailing conditions.

Cooke et al. (1985) support the ideas of Zoght (1978) in stating that interrelationships between the following habitat factors must be considered:

- character of substrate, thickness of sand deposit, degree and nature of salinization; water storage capacity, nutrients, and structure of the substrate or soil; quantity and quality of water available for the plants (such as precipitation regime, soil moisture, air humidity, depth of water- table and it's chemistry); type of movement and rate of displacement of moving sand and dust; exposure to predominant wind direction and solar radiation.

3.2 Methods Used for Sand Dune Stabilization and Control Around the World

Much of the material in this section has been derived from Zoght (1978), and a large number of scientific papers and reports including (Al-Masoodi, 1984; Mohammed, 1984; Saleh, 1984; Shekatreh and Authman, 1984; Tunisian Report, 1984; Morocco Report, 1984; and Sankary, 1987).

This section summarises research and experiments on sand dune stabilization from around the world and is organised in alphabitical order by countries:

Australia: Sand dunes in Australia cover large areas, and include both coastal and desertic sand dunes. The following plants have been used for the coastal sand dune stabilization including (Mitchell, 1974):

- *Ammophila arenaria*
- *Spinifex hirsusta*
- *Agropyron junceum*
- *Ehrharta villosa*
- *Lupinus spp.*
- *Carpobrotus spp.*
- *Acacia spp.*
- *Chrysanthemoides monilifera*
- *Erharta calycina*
- *Medicago sativa*
- *Chloris gayana*
- *Leptospermum laevigatum*
- *Bankasia integrifolia*
- *Casuarina spp.*

Whilst in the desertic sand dunes, the following have been used to improve the stability (Zoght, 1978):

- *Secale cereale*
- *Medicago spp.*
- *Oenotheral biennis*
- *Lupinus digitaris*

All the above mentioned plants gave good results in the stabilization of the aeolian sand dunes, both coastal and desertic, especially when trace elements (Cu and Zn) and nutrient elements (NPK) were added to the sands.

Marram grass (*Ammophila arenaria*) was used as a primary planting for the stabilization of Avalon coastal sand dunes in Australia (Godfrey, 1974). In the second stage of stabilization a wider range of species were used including: *Acacia sorphorae; Acacia cyanophylla; Benkasia integrifolia; Leptospermum laevigatum* and *Westringia fruticosa.*

Fore-dune fences, and mulching with organic materials or chemical products have also been employed for both coastal and desertic sand dunes stabilization. For the stabilization of the coastal sand dunes in Queensland, for example, a trial was designed and installed incorporating three different types of semi-permeable fences - spaced slats, moulded polyethylene material, and woven polyethylene fabric (Barr, 1974). The results of surveys indicated that there was no difference between the rate of sand accumulation against the different types of fences, except that the higher fences eventually accumulated more sand than the lower fences. Approximately 9000 m^3 of sand accumulation per km length of fence occurred over a period of one year.

On the East Coast of Australia a technique called "brush matting" is widely used in conjunction with vegetation, for stabilizing the most exposed areas (Barr, 1974). In this method a single complete layer of tree branches is laid over the bare sand in which grass seeds have been already planted and fertilizer applied. Barr (1974) investigated the relative effectiveness of six mulching treatments, including, brush mat, straw mulch, bitumen emulsion, PVA, combined straw mulch and

bitumen emulsion, and combined straw mulch and PVA. These treatments were applied to small plots which had previously been sown with seeds of marram grass, beach spinifex grass, sorghum, rhodes grass, sand plain lupin, and cereal rye, and fertilized. The plots were laid out in a complete randomised block design with four replications. Seedlings were counted when they germinated, and ground cover was measured at intervals. The results indicated the superiority of the brush matting technique over other types of surface mulching methods to produce stability under very exposed conditions.

China: Coastal sand dunes in China have been stabilized as a first stage using 50 - 100 m wide belts of various trees which are able to survive in saline water. Species used included: *Casuarina equisetifolia; Pandanus odoratissima; Spinifex littoreus* and *Ricinus communis.* The second stage involved the progressive replacement of these with *Pinus tabulaeformis* and *Pinus massoniana.* Desertic sand dunes (about 10% of the total area of the country) have been stabilized through green belts around the oases and other civilian regions using *Salix mongolica* and *Tamarix juniperia.* In the small and limited areas of sand dunes, surface mulches of clay, straw or Kang-Mein stones have been used.

Iran: The total area of sand dunes in Iran is about 2 mha. Due to the encroachment of the mobile sand dunes over the agricultural lands, hundreds of villages have been abandoned. Many airports, railroads, highways and other installations are affected by drifting sand. Mechanical stabilization has been used in Khosistan province using dead plants of *Panicum antidotale; Aristida pennata;* and *Erula galvamifera* erected in (5 - 10 m) checkerboard systems. Oil extracts have also been sprayed on the dune fields before the forestration. 78 different plant species have been employed for sand dune fixation. A variety of species and stages have been used eg. *Haloxylon spp.* seeds; cuttings of *Tamarix spp.* and *Calligonum spp.*

and young plants of *Acacia spp; Zizyphus spp.; Atriplex canescens* and *Prosopis spp.* Most of the mechanical methods of stabilization failed, due to largely to a combination of lack of expertise in designing such systems and the severity of the problem. Vegetation stabilization however, gave good results, especially, through the plantation of *Haloxylon persicum* and *Atriplex canescens* (Sankary, 1987).

Iraq: In Iraq, sand dunes cover an area of more than 8 million Iraqi donums. More information about the origin, causes, weathering conditions and soil characteristics of Iraqi sand dunes; and the methods used for their stabilization will be discussed in chapter 6.

Libya: Two types of sand dunes are extensive in Libya: reddish-brown desertic fine grained dune sands, and white-grey coastal salty coarse grained dune sands.

Experiments on sand dune stabilization were started in Libya in 1916 by the Italian Authorities in order to protect roads from drifting sands. Dry, dead plants including *Imperata cylindrica; Aristida pungens* and *Artemisia herba alba* have been used in fences around the capital, Tripoli, which helped later in growing a very good green belt of forests around this city.

A wide range of chemical materials and oil extracts have been used successfully in sand dune stabilization in many places. In some cases, in order to exploit it for agricultural uses, sand dunes have been treated by a layer of asphaltic material at a depth of 50 - 60 cm before being buried and levelled (Zoght, 1978). The layer of asphalt underneath the sand surface layer reduces soil water evaporation and hence increases water avilability for plant roots. This method gave good results near Tripoli. An ambitious attempt to use aeroplanes to spray a mixture of seeds of herbaceous plants, pesticides, and liquid chemical stabilizers onto the surface of wet sand dunes failed. The reasons for failure are unclear, but lack of expertise is probably in part responsible.

Mauretania: Mauretania, has large areas of mobile longitudinal sand dunes parallel with the Atlantic Ocean Coast including the regions around the capital of Nouakshot. Drifting sand has inundated areas in Nouakshot, Timshkat, Shinkty, Kaifa and Kinkosa cities. Attempts have been made to stop sand migration around Nouakshot by planting with: *Euphorbia balsamifera; Salvodora persica* and *Acacia radiana*; whilst, in the saline coastal areas, *Coccos nucifera; Atriplex farinosa; Haplopyrum mucronatum* and *Sporobolus spicatus* have been used with some success.

Morocco: In Morocco, sand dunes are found in Warzazat, between Zakurah and Mahameed Al-Kizlan, Tunfo and Tarfaia. Plant species and other stabilization techniques that have been used are similar to those that have been employed in the other Northern African Countries such as Libya and Tunisia.

Oman: In Oman, sand dunes exist at least in two regions: desertic sand dunes at Wahiba (Wahiba sands project is still under the study by teams from England and Oman) and the white coastal sand dunes of the Salalah Plain. These latter dunes have been stabilized through planting successive strips of: *Atriplex farinosa; Haplopyrum mucronatum; Prosopis spicigera; Acacia spp.* and *Salvadora persica.*

Saudi Arabia: In Saudi Arabia, sand dunes attacked the regions of Al-Hasa, Al-Hufoof, Al-Mubriz, Bakik and Al-Akik. *Tamarix spp.; Eucalyptus spp.; Prosopis juliflora* and *Parkinsonia aculata*, have been proven most successful in comparison with other plants species (Abdul-Wahed, 1982; Al-Gamidi, 1984; and Abdul-Wahed, 1985). A program of non-irrigated cultivation of *Tamarix aphylla* has been very successful in the Eastern Province of Al-Hasa oasis (Stevens, 1974; Hidore and Abokhair, 1982; and Watson, 1985). At the begining of 1981 about 480 000 woody Tamarix cuttings about 1.0 m long and between 20 and 40 mm in

diameter were planted upright with no more than 50 mm protruding above the surface (Watson, 1985). In order to protect the young plants from the wind, the cuttings were planted between four rows of fences 0.7 - 1.0 m high which were built of date palm fronds (photo 3.1). The survival rates of (125 cuttings at five sites) for the full period of monitoring were from 3.3% for the cuttings on sand dunes, to 35% on sand sheet and 72 - 95% on interdune areas with a near-surface water table. Based upon estimates of the proportional areas of sabkha, sand sheet and dunes on which cuttings were planted, the overall survival rate was 20 - 25%. The success of the scheme may in no small part be due to the fact that during the first three months of 1982 rainfall in the area was almost twice the mean annual total (Watson, 1985).

The ARAMCO oil company has used the procedure of deflection of the moving sand in the Eastern Province in Saudi Arabia to protect isolated buildings and well-heads (Watson, 1985). The technique adopted involved the construction of fences and barriers in two configurations. The first consisted of a fence slanted at about 45^o to the direction of sand drift, the second of a v-shaped barrier pointing into the sand stream. Watson (1985) found that in both cases the degree of protection and the effective life span depends on the porosity and height of the fences. Multiple rows were more effective than single row, especially at high wind speeds (greater than 18 m sec^{-1}).

A wide variety of chemicals including asphalt; synthetic latex; polyvinyl polymers; sodium silicate and gelatine have been utilized as sand stabilizers (Watson, 1985). Most have short effective life span, generally about 1 - 5 years. In order to increase the durability of surface crusts, penetrating liquids have been used.

Crude oil (photo 3.2) and asphalt emulsions presented several disadvantages. For example, they tended to oxidize and lose their effectiveness as binding agents; the effect on the environment was unpleasant with any vegetation quickly being killed; and they were unsightly, producing a black blanket landscape.

Plate 3.1: Palm Fronds Fences (One Metre High) Protecting Young Tamarix Plants From Mobile Sand Dunes in Al-Hasa Oases in Saudi Arabia.

Plate 3.2: The Use of Crude Oil as a Sand Surface Stabilizer in Saudi Arabia.

Curing resins, although more expensive than non-curing oil-based substances, proved to be better sand dune stabilizers and were more acceptable to the public due to the fact they are colourless.

South Yemen (Aden): Sand dunes in Aden exist along the coast of the Arabian Sea. Composed of a fine (0.05 mm) quartzitic sand, they form a longitudinal strip 0.5 - 5.0 km wide, stretching for about 1000 km. Drift from these dunes poses a continual threat to the nearby agricultural lands and installations. As a consequence several attempts have been made to stabilize the dunes.

Trees branches; *Zea mays L.* and *Phragmitis communis* stems as well as living plants of *Saccharum aegypticum* have been used for sand dune stabilization between the capital Aden and Alkad city. The design of the barriers depends on wind direction; where a uni-directional wind prevails, the barriers are erected in parallel lines or strips 5 m apart. Where there is no single prevailing wind directions, the branches are erected in rectangular system of 10 x 30 m units. The length of the branches used is about 70 cm; 20 cm of this is fixed in the sand. *Ammophila arenaria* and *Aeluropis spp.* have successfully been grown between the fences.

Syria: In Syria, sand dunes occur in Al-Kasrah, Dair Al-Zoor, Al-Hasaka, and around Al-Bishri mountain. *Atriplex canescens* and some other local plants have been employed for the stabilization. Recently, Syrian centres specialising in sand dune stabilization and desertification control have tried to multiply species of *Haloxylon persicum; Acacia cyanophylla; Prosopis juliflora; Prosopis tamarugo* and *Atriplex spp.* for the same purpose.

Tunisia: Sand dunes in Tunisia can be divided into two categories: coastal dunes (about 30 000 ha) mainly in the Nephrah and Benzirt regions; and desertic sand

dunes (about 2 200 000 ha) concentrated in the regions of Tuzer, Tatawin and Madanin. Sand dune stabilization in this country was started in 1886 by the French Authorities. They started their experiments with the coastal sand dunes in the Dars region. These were extended later to other regions including, Benzirt, Kaboon, Kabis, Tuzer and some others. Although these attempts generally failed, they provided an important research base enabling successful techniques to be found to stabilize about 2139 hectares of sand dunes by 1911.

Coastal dunes in Tunisia were stabilized, as a first stage, through the erection of foredunes 200 - 300 m in front of the area to be protected from the drifting sands. Behind the foredune ridge, a checkerboard system of 100 x 100 m created from the dead branches and roots of *Arundo donax* or *Saccarum biflorum* were erected. The second stage of stabilization was through the planting of *Acacia cyclopis* near the sea, and *Acacia cyanophylla* as a second line. *Acacia cyanophylla* was replaced later by more economic trees including: *Pinus pinea; Pinus halepensis; Eucalyptus gomphocephella;* and *Eucalyptus camaldulensis.*

Oil extract were unsuccessfully used in the 1960's on coastal sand dunes in the Nephrah and Manzil Belkasim regions. The failure resulted from inadequate dilution of the oil extracts which prevented adequate penetration of the sand surface and hence particle aggregation. Furthermore, the surface layer was not permeable enough for air and water, and thus plants failed to grow.

In the desertic sand dunes, a similar technique was followed, with the following plant species: *Tamarix aphylla; Calligonum spp.; Acacia liqulata; Retama retam; Aristida pingens* and *Nitraria retuse.*

U.S.A.: Drifting sand dunes can be found in most states of the U.S.A. For example, large areas of Arizona, Colorado, California, Texas, Michigan, Massachusetts and Wyoming (Rostler and Kunkel JR., 1964; Cooper, 1969; Lehotsky, 1972; Goldsmith, 1973; and Ahlbrandt, 1974).

In 1893, 120 ha of the United State East Coast sand dunes were successfully stabilized by planting beach grass (*Ammophila breviligulata*) and shrubs together, followed by young pines and other trees (Godfrey and Godfrey, 1974). There is no doupt that the technique of building-up dunes with fertilized *Ammophila spp.* is rapid and effective (Woodhouse and Hanes, 1967). Railways and roads have been protected with tree belts in many places of the United States (Clements et al., 1963).

As well as the construction of fore-dunes by a range of fences or barriers, a number of coastal and desertic sand dune systems in the U.S.A. have been stabilized by spraying one of the following chemical materials as a first stage (Zoght, 1978):

- Asphalt emulsions
- Asphalt cutback
- Elastomeric polymer emulsions
- Polyvinyl alcohol
- Polyvinyl acetate co-polymer
- Sodium acetate

The chemicals were applied when the sands were moist.

In the state of Michigan, for instance, there are about 4 mha of unproductive sandy soils and sand dunes. The sand was levelled after a layer of asphalt was applied at a depth of 60 cm in order to preserve the water reserves of the soil and to make it more available for plant roots. Although this method can be used on a small scale, especially where food production is desirable, it is not recommended for the stabilization of sand dunes covering large areas for the following two reasons:-

1. It is a very expensive method as the first 60 cm depth of the sand must be removed prior to the application of asphalt and then must be returned afterwards.

2. The surface layer of 60 cm depth remains unprotected against wind and water erosions.

Another advanced technique in sand dune stabilization in the U.S.A. has been achieved by aerial spraying seeds of *Andropogan hallii* and *Eragrostis tricodia*. In order for this method to be successful the surface layer must be protected against wind and water erosion (using for example, chemical stabilizers), until the seeds grow successfully to provide vegetation cover.

U.S.S.R: Sand dunes in the U.S.S.R. are found in Turkestan (21 mha); Osbakistan (12 mha); and Kazakhstan (40 mha), movement of which causes many problems for communications, and other civilian installations. Sand dunes have been stabilized by planting *Agriophylium arenarium; Medicago sativa;* and *Lupinus spp.*. Aerial spraying of seeds has occasionally been used.

Tillers of *Haloxylon spp.; Tamarix spp.; Salix spp.;* and *Calligonum spp.* have also been employed for dune stabilization. Railways and roads have been protected with tree belts (Shirmamedov, 1978).

Chemical methods involving spraying an average of 100 - 150 gm m^{-2} of bitumen emulsion coupled with the forestation of the above mentioned trees have also been successfully used.

The above was a short review on the stabilization techniques adopted in many countries. It is also worth mentioning that, several stabilization schemes have been initiated in both Egypt and the UAE. In Egypt, chemical materials including bitumen emulsions; PVAc; PAM; Supergel; Hydrogel (PAM product) and Agrosoc (polymer) and both Absorbent Laminate and Bentonite clay minerals have been used as surface mulches for the aeolian sand dunes (ACSAD, 1984). From these materials, bitumen emulsions indicated their suitability as sand dunes stabilizers when applied at 0.77 - 1.77 l m^{-2}. Although the initial results of using Agrosoc; Hydrogel and Bentonite as surface mulches were reported to be

promising, no data is available about the effectiveness of any of the remaining mulches used. In the UAE, the use of the "liquid clay" as a surface mulch for the mobile sand dunes and the growing of green belts to protect the highways in Dubai is still under the study.

From the foregoing review it is evident that the stabilization of sand dunes both coastal and desertic is a problem confronting many countries of the world. The possible solutions can be summerized as follows:

- The biological stabilization, through various plant species which can survive under the local conditions of each region.
- The mechanical stabilization, through fencing, foredune reshaping.
- Mulching by chemical materials and oil extracts or any other natural mulch, for example, clay, stones and gravels, or dead plant material.

Which of the above solutions is adopted depends on availability of materials, expertise and above all finance.

3.3 Synthetic Soil Conditioners and Stabilizers

3.3.1 Development, Uses and Some Experimental Results

Only relatively recently, have synthetic chemical products been recognized as possible soil conditioners. Many commercial companies have developed and are developing products suitable for soil stabilization. Many researchers have tested the efficiency of various soil conditioners to stop water or wind erosion (Chepil, 1955; Lyles et al., 1969; De Boodt, 1970; Armbrust and Dickerson, 1971; and Moldenhauer and Gabriels, 1972). Such testing has been carried out in both the laboratory using artificial rainfall (Blavia et al., 1971; Gabriels et al., 1973); and in the field experiments on small plots using wind tunnels (Chepil et al., 1963b; Lyles et al., 1969) or artificial rainfall (Mannering and Meyer, 1963; Meyer and Mannering, 1963; Meyer et al., 1972). Encouraging results have been obtained

(Pelishek et al., 1962; Kijne, 1967) involving the stabilization of sands with several polymers and emulsions, eg. polyvinyl alcohol (PVA at 8 gm m^{-2}), polyacrylamide (PAM at 8 gm m^{-2}), potassium silicate (16 gm m^{-2}) and bitucoat (500 ml m^{-2}) (Roose, 1975).

Some of the earliest work on the use of soil conditioners was reviewed in a symposium on "Improvement of Soil Structure" held in 1951 in Philadelphia in U.S.A. by a group of soil scientists. The major topics of discussion at that meeting was a new group of chemical materials which in, small quantities could exert a highly significant stability on unstable soil (Gardner, 1972). Six papers on the stabilization of soil aggregates and on the new chemical materials presented at that symposium were published in Soil Science (1952). Hundreds of scientific papers and reports have since been published on the use of various soil conditioners - 220 papers were reported published during the years 1956 to 1963 (Saini and Hughes, 1975).

The importance of the soil conditioners as stabilizers, was the subject of a special symposium was held in Las Vegas in U.S.A. in 1973 under the supervision of the United States Society of Soil Sciences and the International Society of Soil Sciences. The papers from which were puplished in a special puplication No. 7, of Soil Science Society of America Proceeding. In that symposium possible applications of synthetic soil conditioners for agricultural and non-agricultuarl uses throughout the world were reviewed. De Boodt (1975) suggested that soil conditioner applications in Western Europe might be restricted to bank stabilization on highways and streams, prevention of water erosion on arable land, and to promote germination of sugar beet seeds (*Beta vulgaris L.*). While in arid regions they could reduce evaporation, reclaim saline soils, and prevent water and wind erosion.

In 1981 another special publication about soil conditioners was produced in the Egyptian Journal of Soil Sciences (1981). Also a more recent set of papers

about soil conditioners were published in the Soil Science (1986).

A general review of the use of soil conditioners was produced by Kirkby and Morgan (1980), in which they evaluated the conditioners as soil or sand dune stabilizers against wind and water erosion. In conjunction with previous studies to prevent wind erosion on extremely sandy areas and finer textured soils (Chepil et al., 1960; 1963a), several inorganic and organic materials were examined for their effectiveness when applied directly to the soil surface (Chepil et al., 1963b). Ammonium lignin sulfonate, sodium silicates, calcium chloride, and sodium silicate - calcium chloride mixture were found effective until the first rain when they dissolved and were removed from the soil surface.

Other materials proved more effective reducing wind erosion and dune movement, eg. emulsion of polymerized styrene-butadiene latex in mineral oil was developed by an English company and tested extensively in the early 1960's, a 30% solids of a 9:1 oil:rubber blend, latex-oil material, a resin-in-water emulsion developed by California Firm, and a liquid plastic material developed by a German Firm. (Haas and Steer, 1964; Rostler and Kunkel, 1964; Simmons and Armstrong, 1965; Weymonth, 1967; Gorke and Hulsmann, 1971; and Armbrust and Lyles, 1975).

Eck et al. (1968) used an asphalt mulch in sand dune stabilization in the Southern Great Plains, but, because of the breakdown of the mulch within one year after application, the treatment did not help revegetation.

An experiment in which different rates of chemicals were used to stabilize sand against raindrop impact, was reported by Gabriels et al. (1974). In this the chemicals were either sprayed on the surface or incorporated with the sand. The chemicals and rates applied were: 35 - 100 ml m^{-2} PVAc; 500 - 1570 ml m^{-2} PAM (with and without cross-linker) and 350 ml m^{-2} asphalt were applied at the sand surface. While, 0.5 - 20% PVAc; 10% PAM (with and without cross-linker) and 1.5% asphalt were incorporated with the sand (All the percentages were based on

air-dry sand weight). Polyvinyl acetate, polyacrylamide (with cross-linker) and an asphalt emulsion, applied at optimal rates, appreciably diminished the side splash erosion for dune sand. In the surface application experiment, PVAc (Curasol AE) at a rate of 50 ml m^{-2}, diluted 12 times with water and PVAc (Curasol AH), 35 ml m^{-2}, diluted 18 times, and PAM (with cross-linker) applied at 1 l m^{-2} resulted in excellent stabilization. Small quantities of asphalt emulsion could be used as a mulch on sand surfaces. In the incorporation experiment, 1.5% PVAc (Curasol AE) was found to form stable aggregates.

Wang and Lin (1967) conducted a study on effects of some aggregate stabilizers on soil erodibility. They found that PVA reduced dispersion ratios and was more effective than either organic matter or calcium carbonate as a soil conditioner. Polyvinyl alcohol (PVA) and Polyacrylamide (PAM) polymers have been shown effective in stabilizing Iowa surface clods against rainfall energy received between seeding and a complete cover from the seedlings (Blavia et al., 1971; Gabriels et al., 1973). It was found that PVA and PAM polymers were most effective on subsoils which contained 30% clay. More polymers were required on soils with more or less than 30% clay (Mausbach and Shrader, 1975).

In laboratory experiments by (Schamp et al., 1975) using a large number of either synthesized or purchased polymers. They found that fair aggregation was obtained, when 1 kg of sand was treated after drying with 0.1% PAM in water solution, the water stability of aggregates, however, was very poor. Adhesive polymer bonds between sand particles break while the polymer is dissolving again. Schamp et al. (1975) also found that mixing 1% clay with the sand is sufficient to cause a dramatic improvement in water stability. A few percent of clay has an enormous effect on the stability index, with higher clay contents, still better results are procured. They believe that the clay acts as a kind of filling material in the polymer bonds.

Soils in the Western Plain of Venezuela suffer from crust formation, com-

paction, and physical degradation of the surface. Pla (1975), found that samples of six representive soils, surface treated with conditioners of PAM solution at a rate of 0.16% and hydrophobic bitumen emulsion at a rate of 1.25% had more and larger water stable aggregates and showed a much higher saturated hydraulic conductivity and a lower modulus of rupture than untreated soils.

Carr and Greenland (1975) treated a sandy loam soil with a range of polyvinyl acetate emulsions at rates from 0.03 - 0.12% by weight, sodium carbonate solution was applied to some of the soil samples to simulate alkali soil conditions. They found that emulsion treatment at all rates increased the stability of the aggregates formed on raking during application of the emulsion. Treatment with emulsion produced faster infiltration rates due to the increased resistance of the surface soil to slaking and dispersion. In this experiment rye grass, tomatoes, and barley were grown as test crops. The results indicated a significant increases in yield over plants grown in untreated soil of the same aggregate size distribution. It is likely that intermittent poor aeration produced the conditions that limited the plant growth in the untreated soils.

Effects of soil conditioners on soil surface temperature has been investigated through many laboratory and field work studies (Collis-George et al., 1963; Gurnah and Mutea, 1981; Mahrer and Katan, 1981; and Saleh, 1984). Mulches applied to the surface of a soil affected the albedo, thus white colour mulches decrease the soil surface temperature, whilst black colour mulches increase it. Kowsar et al. (1969) found that the temperature of a soil covered with petroleum mulch at a depth of 1 cm was 5^oC warmer than the bare soil, at the time when the soil temperatures attained their maximum value. Russel (1973) reviewed the effect of various mulches on soil temperature in his book "Soil Conditions and Plant Growth".

The addition of soil conditioners changes the wettability of the soil and results in a more hydrophobic or hydrophilic state. The affinity of soils for water can be

reduced by coating the particles with hydrophobic substances, thereby increasing the apparent liquid-solid contact angle (Letey et al, 1962; Vladychenskiy and Rybina, 1965; Wladischensky, 1966; Rybina, 1967; and De Bano et al., 1967). De Bano (1975) found that hydrophobic substances can affect the flow of water through both saturated and unsaturated soils. De Bano believed that, in saturated soils, higher permeabilities were attributed to a more stable soil structure formed when the fine soil particles were combined into "hard and wet" aggregates. While in unsaturated soils evaporation and infiltration were affected primarily by the hydrophobic coatings on soil particles, a restriction on liquid flow. De Bano also found, that both the chemical nature of the hydrophobic materials and the physical continuity of the particle coating probably affect the magnitude of change occurring in water movement.

In addition to their effects on soil physical properties, chemical soil conditioners may have effects on some of the soil chemical properties. Much less information however, is available concerning the effects of chemical stabilizers on soil chemical properties. Some chemical soil conditioners act not only as stabilizers but also as fertilizers. The effect of soil conditioners on soil chemical characteristics have been investigated by Allison, 1952; Sherwood and Engibous, 1953; Allison, 1956; Buylov et al., 1979; Chen and Katan, 1980; and Bliyev et al., 1981. Work by De Boodt (1975), indicated that, it is obvious that bituminous micelles will adhere to the high salt content spots as a result of the flocculation phenomenon. This is illustrated by an example from the alluvial area on the west coast of Peru where there is an urgent problem related to reclamation of salt affected soils. The problem centred on how the soil could be leached when the infiltration rate is low due to the swelling of clay in the presence of sodium salts. A surface treatment with a bituminous emulsion, at a dose of 1.5%, fixed the soil particles so tightly together that swelling was largely prevented and the infiltration rate was increased by a factor of 3. At the same time, the salt was fixed between the soil particles

and the bituminous micelles, so that the amount of salt coming into solution was decreased at such a rate that plant growth was no longer problematic.

Experiments relating influence of chemical conditioners to plant growth and their nutrient uptake have been carried out by Hedrick and Mowry, 1952; Martin, 1953; Allison, 1952; 1956; Collis-George et al., 1963; Haas and Steers, 1964; Ahmad and Roblin, 1971; Barr, 1974; Phipps and Cochrane, 1975; 1976; Lenvain and De Boodt, 1976; Lenvain et al., 1976; and Buylov et al., 1979. Most of the scientific work relating effects of soil stabilizers to soil physical and chemical properties, and plant growth and nutrient uptake have been summarised in a good review by Saleh (1984).

Field and laboratory studies using large numbers of soil conditioners have established the following criteria for surface soil stabilizers (Armbrust and Lyles, 1975):

i. 100% of the soil surface must be covered,
ii. the stabilizer must have no adverse effect on plant growth or emergence,
iii. erosion must be initially prevented and reduced for at least 2 months,
iv. the conditioners must be easy to apply without special equipment,
v. costs must be low enough for profitable use.

Armbrust and Lyles (1975) indicated that only five polymers (DCA - 70; Petroset SB; Polyco 2460; Polyco 2605 and SBR latex S - 2105) and Coherex- resin in water emulsion were found to meet all these requirements.

Thus in this brief review of the use of soil conditioners, field and laboratory experiments have indicated that only some chemicals are able to improve the characteristics of the treated soils and sand dunes to produce beneficial effects for the plant growth. As the success of using any chemical conditioner or stabilizer depends on soil characteristics, and weathering conditions; it is essential to carry out some laboratory, greenhouse and field tests on the material before it is widely used as a soil conditioner or sand dune stabilizer.

3.3.2 The Role and the Mechanism of Chemical Soil Conditioners on Soil Aggregate Formation

Wind and water erosion, are more effective in soils or in sand dune fields with individual particles than with large aggregated ones. The use of various chemical materials and soil conditioners is aimed at causing the aggregation of soil particles into sufficiently stable units so as to withstand wind and water erosion (Armstrong and Chesters, 1964; Overbeek, 1966; and Vandevelde and De Boodt, 1972).

In order to understand the role and the importance of chemical stabilizers in soils aggregation, it is necessary to understand something of the principles concerning the interaction of the chemical material molecules and the soil particles which bring about binding. The mechanisms have been discussed by (Hallsworth, 1976; and Hannah, 1984), who indicated that there are four types of forces or bonds responsible for holding the ions or molecules on the soil particle surfaces in the initial stages of the adsorption reaction. These are:

1. Ionic bonds, resulting from the transfer of electrons from one atom to another.
2. Van der waals forces.
3. Covalent bonds, result from the sharing of a pair of electrons between two atoms.
4. Hydrogen bonds.

The relative strength of these bonds are compared in table (3.1), and figure (3.1) illustrates some of these mechanisms. From these illustrations it is clear that the collection of ions remains overall electrically neutral.

The strength of the bonds shown in table (3.1) decrease in the following series:

Ionic bonds > Covalent bonds > Hydrogen bonds > Van der waals "bonds".

The ionic bonds occur as a result of charge deficits at the edges of the crystalline sheets on the silicate lattices of clay minerals. They will also occur across

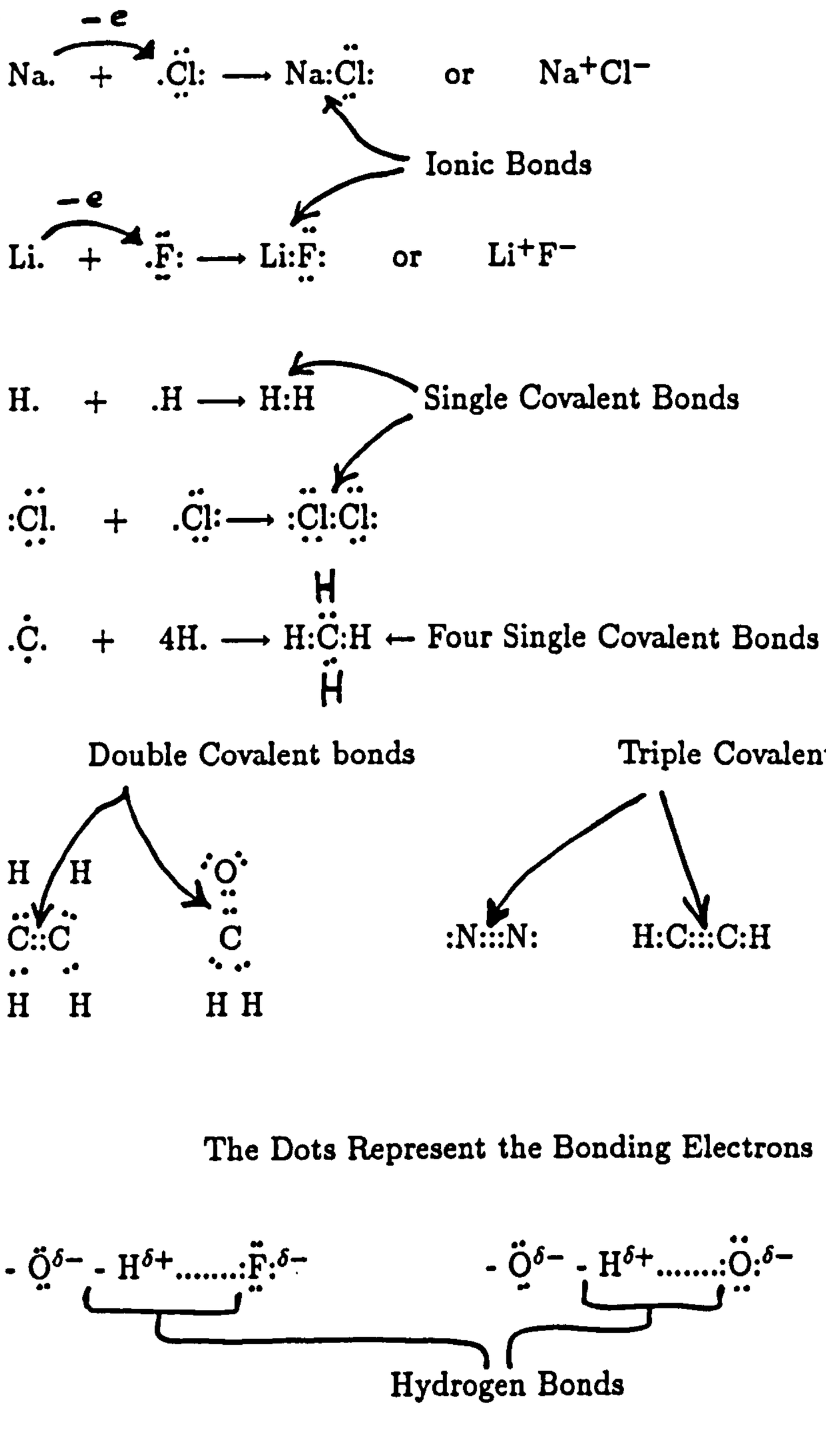
Table 3.1: Comparison of Some Bond Strengths (From Hallsworth, 1976).

Ionic Bonds	Li F	238.9 k.cal mol^{-1}
	Cs I	134.9 k.cal mol^{-1}
Partial Ionic Bonds	C - H	87.3 k.cal mol^{-1}
	O - H	110.2 k.cal mol^{-1}
	F - H	147.5 k.cal mol^{-1}
Single Covalent Bonds	C - C	58.6 k.cal mol^{-1}
	H - H	103.4 k.cal mol^{-1}
	N - N	23.0 k.cal mol^{-1}
Hydrogen Bonds	K - H.....F	6.7 k.cal mol^{-1}
	O - H.....O	4.5 k.cal mol^{-1}
	N - H.....N	1.3 k.cal mol^{-1}
Van Der Waals "Bonds"		$\simeq$ 1.0 k.cal $bond^{-1}$

the surfaces between layers as a result of isomorphous substitution of a cation of one element by another cation of lower charge (Hallsworth, 1976). Hallsworth added that the magnitude of the charge on the adsorbed surface need not be equal with the charge deficit or excess on that part of the surface on which it is adsorbed. When the adsorbed cation has greater charge than the deficit at the adsorption site, the excess positive charge can in turn serve as an adsorption site for a negatively charged grouping. Calcium and iron ions, adsorbed on to a silicate surface, could subsequently act as adsorption sites for organic or inorganic negatively charged surfaces.

The above mentioned phenomenon will lead to crystal growth. If, for ex-

Figure 3.1: Mechanisms of Various Bond Types (From Hendrickson et al., 1970; Morrison and Boyd, 1973; and Fessenden and Fessenden, 1979).



The Dots Represent the Bonding Electrons

ample, the edges of a kaolinite particle were initially negatively charged and adsorbed a trivalent aluminium ion, or any other divalent or trivalent cation, the lattice would become positively charged. While the adsorption of silicate anion subsequently will lead to negatively charged sheet edge again. Hallsworth indicated also that the crystal lattice will continue to grow, unless some change in the particle environment occurs to stop this phenomenon from continuing.

The Van der waals forces are important in surface reaction because they arise from interaction between atoms or molecules responsible for the adherence of microscopic size particles to each other in the absence of special forces of repulsion (Hallsworth, 1976). Although the Van der waals bonds are capable of acting at long range, the magnitude of the attractive form falls rapidly with distance, they are negligible after the distance of about 1.5 mμ (Kitchener and Prosser, 1958) (cited by Hallsworth, 1976).

A covalent bond is the sharing of two atoms in a pair of electrons. It requires the presence either of a donor atom on the surface of the soil particle and an acceptor atom in the ion or molecule adsorbed, or vice versa. Hallsworth (1976) indicated that the organic macromolecules released by the decomposition of added organic matter or conditioners possess a variety of groupings containing donor atoms. While on the proteins and the polysaccharide lattices, the nitrogen, sulphur, and carbonyl atoms of the amine, imidazole, cystein, carbonyl, and amino sugar residues, and the carbonyl groups of the uronic acid anhydrides and the lignins can all act as electron donors.

In the hydrogen bond there are two electronegative atoms with a hydrogen ion between them (Hendrickson et al., 1970). Hendrickson et al. added that it is essentially electrostatic or ionic in character and relatively weak (3 to 5 k. cal. mol^{-1} in common cases), but it is of importance in soil structure formation that the lattices of the clay minerals provide the chance of hydrogen bonding arrangements to develop between two surfaces. Hallsworth (1976) indicated that

the oxygen nets of the inorganic lattices provide acceptor sites for hydrogen bonds, whilst the hydroxyl nets provide donor sites. This state is clear in kaolinite clay mineral, and always leads to the formation of multi-layer crystals.

How can soil particles be aggregated ?. This question had been discussed by (Schamp, 1976), who indicated that soil particles consist of mainly two chemicals namely, quartz and alumino-silicate sheets. Quartz is present in soils as more or less spherical particles with diameter between 1 μm and 1 mm, and alumino-silicate sheets seldom exceeding in thickness 1 μm per sheet.

The alumino-silicate sheets carry electrical charges which lead to the first form of "aggregation" as a result of the interaction of their electrical charges with metal cations. Schamp indicated that in some cases, as in kaolinite clay mineral, the sheet packing resulting from the above interaction is sufficiently strong to be permanent. While, in other cases, as in montmorillonite, the strength of the stack depends on the type of cations present; for example, it is strong enough with calcium ions, while it opens up to individual sheets with sodium ions as a result of dispersion phenomenon caused by sodium ions (Richards, 1969; and Al-Ani, 1980).

Flocculation of the small flat clay crystals into clay domains is another type of aggregation. Schamp (1976) illustrated that electrical interactions between both the negatively charged surfaces and the positively charged edges from clay mineral particles are responsible for irregular crystals aggregation by forming strong or weak aggregates with diameters of a number of microns. With the formation of the fine particles aggregates these are thought to form bridges between larger particles and stabilize the entire soil matrix in large aggregates (Brandt, 1969). An increase in the amount of moisture or soluble salt present at the surface tends to stabilize the surface by increasing the number of bonds between individual grains (Nickling, 1978).

Although clay minerals are negatively charged, these charges are much too

weak to bind the surfaces of the quartz particles and clay domains together. Hence, the necessity of using intermediate chemicals or natural soil stabilizers to gather clay-sand or sand-sand particles together, is of great importance (Schamp, 1976; and Hannah, 1984). For example, organic polymers including polysaccharides, proteins and lignins, all contain enough polar groups in order to provide good adsorption between quartz and clay domains. These materials should have enough flexibility to contact soil particles over a large area, and yet still be coherent enough to withstand wind and water erosion. Figure (3.2) is a model of a soil aggregate stabilized by organic matter or by soil conditioners showing clay domains, organic matter, polymers and quartz (De Boodt, 1979).

Harris et al. (1966) envisaged three basic mechanisms as controlling polyanion-clay linkage:

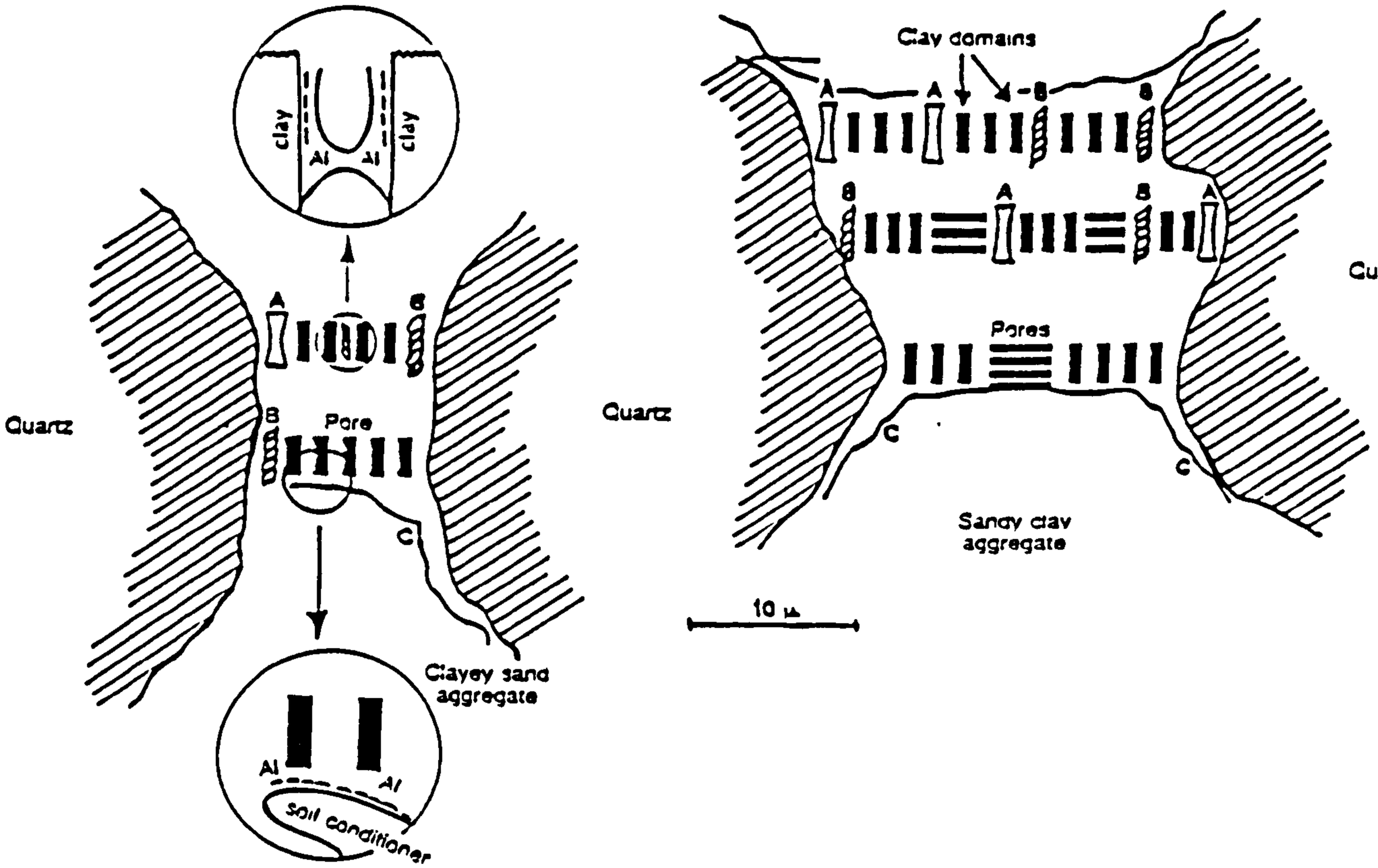
i. bond formation between negatively charged carboxyls of the polymer and positively charged clay edges,

ii. hydrogen bond formation between polymer carboxyls or hydroxyls and free hydroxyls or oxygen atoms of the clay, and

iii. formation of a cationic bridge between the polymer carboxyls and the negatively charged clay surfaces.

It is thought that artificial soil conditioners operate in a similar way. In studies of the adsorption of polyvinyl alcohols (PVA) and polyethylene glycols (PEG) by montmorillonite (Greenland, 1963; Emerson and Raupach, 1964; and Parfitt and Greenland, 1970) and silica (Howard and McConnell, 1967), the polymers were in all cases strongly adsorbed. Greenland (1972) suggested that the adsorption energy of PVA was derived from hydrogen bonding between the hydroxyls of the polymer and the oxygen atoms of the silicate. While, Imoto and Nakamura (1969) have suggested that a contribution from Van der waals forces may occur. The hydrogen bond formation can be attributed to polymers active functional groups (-OH, -COOH, -NH2, -C≡N, etc...) with -OH groups of soils

Figure 3.2: Model of Soil Aggregate Stabilized by Organic Matter or by Soil Conditioners Showing Clay Domains, Organic Matter, Polymers and Quartz. The Size of Clay Domains is Strongly Exaggregated: A = Weak Linkage Due to Water Meniscus; B = Linkage Due to Humus or Sesquioxides; C = Linkage Due to Micelles or Polymers (Soil Conditioners). Dotted Lines Indicate H-Bonding. Notice Also the Role of Aluminium Ions. Magnified Inserts: Organic Matter-Clay Interaction or Polymer-Clay Interaction (From De Boodt, 1979).



(French et al., 1954; Holmes and Toth, 1957; Kachinsky et al., 1967; Kachinsky and Mosolova, 1976; Vasyliev, 1976; and Vasyliev and Malygina, 1976).

Griot and Kitchener (1965) found that newly exposed silica surfaces adsorbed

PAM, while ageing of the silica lead to hydration of the surface, and the PAM was then not adsorbed. Greenland (1972) found that PVA was strongly adsorbed by silicas immediately after ignition at 800^oC, while unignited silica did not adsorb PVA. Greenland also found that the adsorption of polyelectrolytes is more complex than for uncharged polymer adhesion with soil particles. There is usually strong adsorption of oppositely charged surfaces. Greenland (1972) added, since the net surface-segment energy is usually large, the charged polymers will normally fall upon the charged surface.

There is however, a fundamental difference between the mode of action of soluble and emulsified adhesives (Vandevelde and De Boodt, 1972; and Gabriels et al., 1975b). Polymer solution consists of a complex of filmy and fibrous networks linking the particles together like a coat of paint by strands of soil conditioner material. A stable adhesion between soil particles and polymer requires that the polymer be sufficiently large but flexible and extensible so that the best orientation is obtained for establishing a large number of points of contact with the soil particle, and an ability to penetrate and stabilize the pores between clay domains and micro-aggregates ($< 100\ \mu$) (Greenland, 1963; 1965). In the case of emulsions, the electrically charged spherical micelles move to the meniscus, building up stable bridges in the contact points of the soil particles when the soil is drying out (De Boodt, 1970 and Vandevelde and De Boodt, 1972). Rigol and De Bisschop (1972) attributed greater effectiveness of emulsions than solutions in soil aggregation to the higher values of emulsion surface tension and liquid-solid contact angles between the emulsion and soil particles.

Thus, in summary the formation of soil aggregates by soil chemical conditioners involves the interlinking of soil particles either: (i) through the electrostatic linkage between the cationic or anionic soil conditioners either with negatively charged clay surfaces or with the adsorbed divalent or trivalent cations on the clay particles; or (ii) through, the non-ionic conditioners which can make linkages

with the soil particles either through the Van der waals forces or through the formation of hydrogen bonds between the functional groups of polymers including (-OH, -COOH, -NH2, -C≡N, etc...) and the active sites of the soil particles (De Boodt, 1979). The quality of soil aggregates formed will depend upon the strength of these bonds, as measured by and their resistance against wind and water erosion (Schamp and Huylebroeck, 1972; and Voronin, 1976).

CHAPTER 4

MATERIALS AND METHODS

4.1 Introduction

This study was designed to investigate the suitability of two techniques available for stabilizing sands in both coastal and arid environments, namely the use of vegetation and the use of mulches involving various chemical stabilizers. The experimental design involved both field and laboratory studies. Two locations were selected as suitable field sides, these were the coastal sand dune area at Druridge Bay, Northumberland (UK) and the Baiji drifting sand area of central Iraq.

4.2 The Study Sites

4.2.1 The Druridge Bay Sand Dunes

Druridge Bay sand dunes were chosen as a suitable area for the study of coastal sand dune stabilization, for a number of reasons:

1. Druridge Bay sand dunes are part owned by the National Trust and part owned by the Northumberland County Council, both of whom are concerned about increasing erosion of the system. They were therefore willing to give both permission and assistance for the field work programme.
2. The concern for the increased incidence of erosion arises from the fact that the dunes provide an effective barrier between the sea and adjacent low lying land. Without this barrier regular inundation during storm tides would be inevitable.
3. Drifting sand could cause problems for the farm land and buildings adjacent to the dunes.
4. The sand dunes are typical of many coastal dune areas around Britain and the coasts of Europe, thus any research findings should be applicable to many

of these other localities.

5. A final point in favour of the Druridge Bay dunes was that they are the most extensive dune system readily accessible to Durham.

4.2.2 The Baiji Sand Dunes

Baiji sand dunes system in central Iraq was chosen for the following reasons:

1. The total area of sand dunes in Iraq is more than 8,000,000 donums (1 Iraqi donum = 2500 m^{-2}), in which Baiji sand dunes (220,000 donums) form one of the most important mobile fields in the country.
2. Drifting sands at Baiji pose a serious problem for the communities, farmlands, factories, roadways, railroads, airports and other installations in the area.
3. Because of these problems the Ministry of Agriculture and Irrigation is actually involved in researching techniques for stabilizing the dunes and thus was very supportive of the research project.
4. The dunes are typical of those in the rest of Iraq, and indeed probably of many arid areas, thus any findings from this study could have a widespread use.

4.3 Selection of Plant Species

As noted in chapter 3 (sections 3.1.4 and 3.2) many plant species have been used successfully in both coastal and desertic sand dune stabilization schemes. To attempt to use all such plants was impossible in the time available, thus a selection was made in which species reported to have been used in Iraq and the UK were chosen. Whilst marram grass (*Ammophila arenaria*), lyme grass (*Elymus arenarius)* and rye grass (*Lolium spp.*) were readily available in the UK*. A

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* *Seeds of both rye grass species (Merlinda spp. and Melion spp.) were supplied by Nickerson's Ltd., Grimsby. Marram grass seeds and tillers and lyme grass tillers were collected from Druridge Bay coast area.*

request to Kew Garden, Edinbrugh Botanic Garden and the Baiji Sand Dune Stabilization Station in Iraq for seeds of 9 species@ suitable for Iraqi conditions, produced seeds of only *Eucalyptus spp.; Acacia spp.* and *Panicum spp.*. These latter 3 are reported by (Hannah, 1984; Mohammed, 1984; and Saleh, 1984) to be some of the most successful plants in the stabilization of desertic sand dunes in Iraq. Whilst, marram grass (*Ammophila arenarea*) followed by lyme grass and rye grass are the most popular plants in the U.K. coastal sand dune stabilization schemes.

4.4 Selection of Chemical Stabilizers*

In this study of sand dune stabilization, the chemicals listed in table 4.1 were selected for initial laboratory and greenhouse trials, the selection was later reduced for the field experiments.

The choice of chemicals was based firstly on an extensive literature review (see below) on which the first 7 chemicals plus bitumen emulsions were reported to have been successfully used in a range of environments. Secondly, they could be

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@ *These included Tamarix spp.; Eucalyptus spp.; Casuarina spp.; Acacia spp.; Euphorbia balsamifev; Panicum spp.; Ricinus commims; Artimisia scopari and Sinondsia chinensis. Only the seeds of Panicum spp.; Eucalyptus microtheca and Acacia cyanophyla were supplied by Baiji Sand Dunes Stabilization Station in Iraq.*

* *De Boodt (1975) defined "***soil conditioners***" as giving "soils the needed physical properties to allow plant growth, fight erosion, or save water". Jassim (1983) identified "***soil conditioners***" as "organic or chemical materials that improve one or more of the soil characteristics". These two definitions are too general for the purpose of sand dune stabilization as the materials in both could lack the long term stabilization that "***soil stabilizers***" have. More details of this division will be discussed later.*

Table 4.1 : Chemical Materials Used in This Study.

No.	Chemicals	Abbreviations
1	Polyvinyl alcohol (14,000)	PVA1
2	Polyvinyl alcohol (125,000)	PVA2
3	Polyethylene glycol (4000)	PEG3
4	Polyethylene glycol (400)	PEG4
5	Vinamul 3270	V1
6	Vinamul 3277	V2
7	Vinamul 18207	V3
8	Ferquatac emulsion RB50	F.E.
9	Bitumen emulsion A1-50	B.E.
10	Aquapol 35-0019	Aq1
11	Aquapol 35-0031	Aq2

used as bses for comparison with three, newly produced chemical resins - Ferquatc emulsion RB50, Aquapol 35-0019 and Aquapol 35-0031 which were being tested for the first time. It should be noted that Aquapol 35-0031 was only released for trials very late in this research, and thus it has not been used in all the reported tests.

The choice of the previously used stabilizers was based on the following literature review: PVA; PEG; Vinamul 3277 and bitumen emulsions have already been used as soil conditioners or sand dune stabilizers in many other studies (Gabriels, 1972; Hanafi et al., 1975; Carr and Greenland, 1975; Gabriels et al., 1975; and Saleh, 1984). In a series of experiments Stefanson (1973) has shown polyvinyl alcohol (PVA) to be an effective stabilizer of surface soils from Australia, namely, Urrbrae series (45% sand; 36% silt and 19% clay), Nuriootpa series (78% sand; 11% silt and 11% clay), Tarlee series (45% sand; 31% silt and 24% clay) and Riverton series (31% sand; 35% silt and 34% clay). Stefanson (1973) also found that,

the acceptance of simulated rain could be doubled by adding 0.005% w / w of PVA to the top 0 - 2 cm of the undisturbed cores from Urrbrae, Nuriootpa and Tarlee soils. The efficiency of stabilization was enhanced by use of the optimal-sized polymer and application to wet soil.

From soil column experiments, Gabriels (1972) concluded that an artificial stabilizing treatment with either 0.15% PVA or with 1.5% bitumen emulsion could be very effective in increasing the drainage water of a saturated loamy soil. This artificial stabilization of the aggregates keeps the hydraulic conductivity and the outflow high and the water retaining capacity low.

Carr and Greenland (1975), used two samples of PVA in a test of structural improvement of sodic soils. The two PVA's used were PVA15000 and PVA100000 and each contained 12 residual acetyle groups per 100 segments. 1% aqueous solutions were prepared by adding the solid polymer to cold water and then heating to 70 - 80°C with vigorous stirring. They found that the polymer of higher molecular weight was apparently effective in very small amounts (0.04%).

Hartmann et al. (1975), in their study of "the effect of nonionic surfactants on the penetrability in sand and silt loam treated with different soil conditioners" used polyacrylamid (PAM) 0.2%; polyvinyl alcohol (PVA) 0.2% and bitumen emulsion (Humofina) 0.8%. The moisture content of the soils after application was about 20% by weight for the sandy soil and 25% for silt loam soil. In the sandy soil, the water intake was lower in the treated samples than in the untreated ones, and even zero in the sand treated with bituminous emulsion. While, in the silt loam soil, there was only an increase in infiltration rate when the wetting agent Aqua-Gro (50% polyethylene ester + 50% polyethylene ether) was applied to the soil in a mixture with a hydrophobic product (asphalt emulsion).

Using a soil of (23.9 clay; 65.9% silt and 10.2% sand) and the wet-aggregate distribution as an erodibility index for conditioned soils. Gabriels et al. (1975), used concentrations of (0.1% and 0.2%) and (0.05%; 0.1%; 0.2% and 0.4%) for

polyethylene glycol (PEG) and polyvinyl alcohol (PVA), respectively. Initial and final soil moisture contents were (10% - 15%) and (20% - 25%), respectively. After one hour of rainfall (50 - 60 ml hr^{-1}), PVA resulted on less erosion comparing with the PEG in both total wash erosion (W) and total splash erosion (St).

In a study by Verplancke et al. (1976), soil materials of dune sand, a loamy sand and a silt loam were used to assess the effect of soil conditioners on their water transmission properties. Large air-dry soil samples were passed through a sieve so that all aggregates were smaller than 8 mm diameter. When brought to the optimal moisture content of (20%) for soil aggregation (De Boodt, 1972), the wet soil samples were treated with PAM 0.2%; PVA 0.2% and bituminous emulsion 1.5%. With both dune sand and loamy sand, the infiltration rate decreased in the samples treated with both PVA and PAM. While, in the silt loam soil treated with PVA or PAM, the infiltration rates were much higher than the untreated natural soil (about 2 times). The hydrophobic bituminous emulsion decreased the infiltration rate (about 4 times) of the silt loam soil.

The use of bitumen emulsions as soil stabilizers had been suggested by De Boodt (1970). Gabriels et al. (1974), indicated that a small quantity of emulsion (0.35 l m^{-2}) highly diluted with water can be used as a mulch on sand surfaces. The high dilution enables the bitumen micelles to migrate and penetrate deeper under the sand surface linking sand particles together after drying. Gabriels previously (1972), indicated that a high concentration of bitumen emulsion 0.5 - 1.0 l m^{-2}(diluted 0.5 - 1.0 time with water), when sprayed on small loamy soil clods (2 - 8 mm), showed some effctiveness in decreasing total soil loss. The treatment with a low concentration of the bitumen (0.25 l m^{-2}diluted 5 times with water) was not effective.

Rabines Flores (1972), sprayed 1000 gm of each of four saline sandy loam soils with 15 ml of humofina B2864 diluted in 45 ml of water. Air-dry treated aggregates < 2 mm were used for the hydraulic conductivity test. The hydraulic

conductivity increased 7 - 9 times for three of the treated samples and twice for the fourth as compared to untreated soils.

Hanafi et al. (1975), sprayed and mixed an originally 50% bituminous emulsion (Humofina), previously diluted three times with water, at a rate of 60 ml kg^{-1} of a heavy clayey compacted soil. The soil was cultivated with cotton plants. The results indicated increases in both the Bruto and Netto* yields, and the total number of seeds in the soil treated with the bitumen compared with the untreated one.

Pla (1975) added bituminous emulsion to six Venezuelan soils (different in their textures) as a 12.5% dilution in water at a rate of 1.25% by weight. At this rate of application, the hydrophobic asphalt emulsion seemed to be most effective for improving and stabilizing the aggregates of the surface soil against the effects of raindrop impact and for preventing compaction under moisture conditions unfavorable for tillage operation.

Gabriels (1976) evaluated the following treatments as soil conditioner mulches to prevent erosion from a dry loamy sand soil:

- PAM 20 gm m^{-2}diluted with water to 1.1 l m^{-2},
- PAM 10 gm m^{-2}diluted with water to 0.8 l m^{-2},
- bitumen emulsion 150 ml m^{-2} diluted with water to 1.7 l m^{-2},
- bitumen emulsion 100 ml m^{-2} diluted with water to 0.9 l m^{-2}.

The results indicated that, PAM 20 gm $m^{-2}$was effective in reducing the soil loss by 40% - 50% during the first six months with 200 mm rainfall. Bitumen emulsion was not desirable for erosion control when applied as a surface mulch, as the hydrophobic character of the bitumen resulted in more runoff than the control. Higher concentrations of bitumen emulsions should be applied as surface mulches to get better stabilization for soil aggregates against erosion.

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* *Bruto yield consisted of cotton fibers, seeds and flower cups. While, Netto yield is only the weight of cotton fibers (Hanafi et al., 1975).*

Three of bituminous emulsion treatments were tested on the aggregate stability and water infilitration capacity of a saline soil from Tunisia (43% clay; 22.4% silt and 34.6% sand). The doses were: 1.00%; 1.33% and 1.66% corresponding respectively to 0.75 l m^{-2}; 1.00 l $m^{-2}$and 1.25 l m^{-2}[considering a soil layer with a thickness of 6 cm and a bulk density of 1.25 (De Waele, 1976a)]. The soil had been pre-moistened in such a way that the moisture content after treatment was optimal (about 21%). The combination of the greatest dose (1.66%) and the greatest dilution (10) gave the best results. This treatment was significantly different from all the others with the exception of the treatment 1.33% dilution (5). In another study, De Waele (1976b) used the following treatments:

- Untreated soil,
- 0.5 l bituminous emulsion + 1.0 l water per m^2,
- 1.0 l bituminous emulsion + 2.0 l water per m^2, and
- 1.5 l bituminous emulsion + 3.0 l water per m^2.

De Waele found that, the bituminous emulsion added at rates up to 1.5 l m^{-2}improved the aggregate stability for at least six months after application.

To evaluate the effect of surface mulching of both bitumen emulsion and PAM on evaporation of water from a bare sandy loam soil. Hartmann et al. (1976) used anionic asphalt emulsion (bitumen) and PAM at rates of application equal to 150 ml m^{-2} and 20 gm m^{-2}, respectively. The results indicated that, the bare soil rapidly lost water in the upper 30 cm. The mulch-covered soils were very effective in reducing the evaporation at the initial stage of the drying process, but later on lost their effectiveness.

De Boodt and De Vleeschauwer (1981) in their windtunnel study on the "effect of various soil conditioners as mulches on the resistivity of a sandy soil against wind erosion" found that both bitumen (75 gm m^{-2}) and PAM (20 gm m^{-2}) stopped soil losses completely in comparison with the losses (5.2 and 28.3 kg ha^{-1}) from the control, when they were exposed to windspeeds of 17 and 22 km

hr^{-1}at a height of 2 m. De Boodt and De Vleeschauwer therefore, argued that it will be a matter of economics to decide which treatment is the most effecient and economically justified for the needed control of wind-erosion.

Callebaut and De Boodt (1981) used bitumen emulsion (50 gm m^{-2}) and PAM (20 gm m^{-2}) as surface mulches to evaluate their effects on the temperature of a sandy loam soil. They found that a considerable net increase of heat content was regularly obtained under the mulched zone of the soil where seedling emergence can be expected to be most active.

A surface sample from Tahrir sandy soil in Egypt was treated with 0.0%, 0.5%, 1.0% and 1.5% bituminous emulsion; 0.0%, 0.25%, 0.5% and 1.0% curasol AH and 0.0%, 0.05%, 0.1% and 0.2% PAM + glyoxal (Tayel and El-Hady, 1981b). Regarding the effect of the studied conditioners on the structural stability of the treated soil, 1.0% of either bituminous emulsion or curasol AH and 0.2% PAM + glyoxal were recommended. In another study of erosion control and stability of soil aggregates, Tayel et al. (1981c) treated three soils (sandy, sandy loam and calcareous) with bitumen emulsions (0.25%, 0.5%, 1.5% and 2.0%); PVAc (0.125% - 1.5%) and PAM (0.05%, 0.1%, 0.15 and 0.2%). They found that soil conditioning increased the stability of aggregates larger than 0.25 mm in diameter. Soil erosion decreased with increasing the application rates. The response to the chemical treatments varies with the soil type, conditioner used, and the application rate.

A report from ACSAD (1984), examined the use of different types of bituminous emulsions (B.E.) in sand dune stabilization in Egypt. The emulsions were B.E. by Petroleum Research Institution in Egypt; B.E. (Humofina) by Petrofina Co. in Belgium and B.E. (Curasol) by Hockest Co. in West Germany. They were sprayed on the sand within ranges of 0.0 - 1.5% . All types of bitumen gave good results, the percentage of the stable aggregates more than 2.0 mm were 92.7% under the effect of 1% emulsion. 96.8% of stable aggregates of the same diameter were achieved with 1.5% bitumen emulsion.

In general, spraying an asphalt film (mulching) or mixing asphalt with the top-layer of the soil can be a way to prevent wind and water erosion. The amount of asphalt used for this purpose varies from 0.5% to 1.5% on weight basis of soil (Gabriels et al., 1975).

From the above literature review, it is obvious that three chemicals in particular PVA; PEG and bitumen emulsions have been used successfully in many studies both as soil conditioners or as sand dunes stabilizers (Carr and Greenland, 1975; Roose, 1975; Hanafi et al., 1975; De Waele, 1976a; and Tayel and El-Hady, 1981b). Concentrations used from PVA and PEG both as soil conditioners or as sand dune stabilizers range from (0.005% - 0.4%) and (0.1% - 0.2%), respectively (Stefanson, 1973; Gabriels et al., 1975; Hartmann et al., 1975; Roose, 1975; and Verplancke et al., 1976). The recommended concentrations for bitumen emulsions as sand dune stabilizers were (0.77 - 1.77 l m^{-2}) by ACSAD (1984), and 0.7 l $m^{-2}$by Ayton Asphalte Ltd. (the producer of bitumen emulsion A1-55).

Field experiments at Hillend and greenhouse or plot experiments at Swansea (U.K.), showed that Vinamul 3277 (20 - 40 ml m^{-2}), bitumen emulsion (100 - 2000 ml m^{-2}), bitumen emulsion with latex (100 - 1250 ml m^{-2}) and to a lesser extent bitumen emulsion + calcium lignosulfonate ([100 + 38] - [500 + 187] ml m^{-2}) were most effective as sand surface stabilizers against the effects of wind and rain (Saleh, 1984). Saleh also, indicated that calcium lignosulfonate, ammonium lignosulfonate and polyacrylamide treatments were ineffective as soil stabilizers because they were leached out by rainfall, and were also toxic to plant growth at higher levels of application.

Thus of all the materials described in the literature, PVA; PEG; Vinamul and bitumen emulsions have all shown some degree of effectiveness in stabilizing sandy soils and dune surfaces. Hence these were selected for further study.

4.5 The Selection of Chemical Concentrations to be Used in the Laboratory, Greenhouse and Field Trials

Of critical importance in any use of soil surface stabilizers which are to be succeeded by vegetation, is the effect that they may have on the infiltration rate of water into the soil since it is vital that water can reach the plant roots. Following the infiltration technique explained in section 5.1.2.2 and using the information from previous work (section 4.4), PVA1; PVA2; PEG3 and PEG4 were tested at rates of 0.1%; 0.2% and 0.4% (on air-dry sand basis), while, the bitumen emulsion A1-55 was tested at rates of 0.5; 1.0 and 1.5 l m^{-2}. Vinamuls 3270; 3277 and 18207 (V1; V2 and V3) were tested at the concentrations of 50 ml m^{-2} and 100 ml m^{-2} . These are slightly higher than the concentrations used by Saleh (1984) for the Vinamul 3277 (20 - 40 ml m^{-2}). This is because the selected concentrations of Vinamuls were found to be effective in producing stable sand aggregates than those used by Saleh (1984), furthermore the new concentrations of Vinamuls did not cause any serious water infiltration problems.

The results indicated that all the selected concentrations for PVA1; PVA2; PEG3; PEG4; Bitumen emulsions; V1; V2 and V3 permitted water infiltration. The concentrations of PVA1; PVA2; PEG3 and PEG4 used, increased infiltration rate, whilst, the concentrations of bitumen emulsions; V1; V2 and V3 reduced the infiltration rate. The reduction in the infiltration rate increased with the increases in the chemicals concentrations. One sample from the three replicates of 1.5 l $m^{-2}$of bitumen emulsion was impermeable due to the formation of a thin, impermeable layer of bitumen at the lowest point of bitumen penetration depth. Hence, only the 0.5 and 1.0 l $m^{-2}$of bitumen emulsions were used in further laboratory, greenhouse and field tests. As all the tested chemicals concentrations gave infiltration rates that were in excess of the minimum acceptable standard of 0.25 cm hr^{-1} as stipulated by the United States Salinity Laboratory Staff (Richards, 1969); no special water management problems render any of the treatments un-

suitable for irrigation enterprises. Thus, the concentrations illustrated in table (4.2) for PVA1; PVA2; PEG3; PEG4; V1; V2; V3 and bitumen emulsions were used in all the further studies on Druridge Bay sands.

Table 4.2 : Chemical Materials Used and Their Application Rates

Chemicals (abbr.)	Application Rates*
PVA1	0.2%; 0.4% (52.2;104.4 gm m^{-2})
PVA2	0.2%; 0.4% (52.2;104.4 gm m^{-2})
PEG3	0.2%; 0.4% (52.2;104.4 gm m^{-2})
PEG4	0.2%; 0.4% (52.2;104.4 gm m^{-2})
V1	0.05; 0.10 l m^{-2}
V2	0.05; 0.10 l m^{-2}
V3	0.05; 0.10 l m^{-2}
F.E.	0.2; 0.4 l m^{-2}
B.E.	0.5; 1.0 l m^{-2}
Aq1	0.33%; 0.66% (86; 172 gm m^{-2})
Aq2	200; 250 gm m^{-2}

* All (%) are on the base of air-dry sand.

As none of the new chemicals i.e. Aquapol 35-0019 (Aq1); Aquapol 35-0031 (Aq2) and Ferquatac emulsion RB50 (F.E.) has been used for stabilization purposes before, no data was available concerning application concentrations and permeability. Thus series of experiments were carried out to determine the maximum concentrations of all three chemicals which allowed infiltration to occur*. For Aq1; Aq2 and F.E. concentrations of 0.5%; 0.75%; 1.0%; 1.5%; 2.0%; 2.5% and 3.0% on air-dry sand weight; 150; 175; 200; 300 and 600 gm $m^{-2}$and 0.5; 1.0 and 1.5 l m^{-2}respectively were used. The results showed that for Aq1, only

* *For details of the method used see section 5.1.2.*

the lowest concentration 0.5% (later found to be 0.66% following the previously illustrated procedure); for Aq2, the concentrations of 200 gm $m^{-2}$and less (later found to be 250 gm m^{-2}following the same procedure) and for the F.E., the lowest concentration of 0.5 l m^{-2}were permeable. All other concentrations did not allow any infiltration at all. Thus for further experiments Aq1 concentrations of 0.66% and 0.33%; Aq2 concentrations of 250 gm $m^{-2}$and 200 gm $m^{-2}$and F.E. concentrations of 0.4 l $m^{-2}$and 0.2 l m^{-2}were used (table 4.2).

All the chemicals illustrated in table (4.2) were prepared or diluted with water to obtain the specified concentrations when applied at a rate of 6.0 l m^{-2}. This rate of application was chosen because, from a practical standpoint, it enabled an even application over a square metre to be achieved using either a pressure spray or sprinkler. The high dilution with water also enabled the chemicals to penetrate the sand surface for a depth of 1.6 - 2.0 cm, thus giving a good depth of mulch. The small differences in the mulch depths was due to the sand moisture contents. The higher the moisture content, the thicker the mulch produced from the same volume of the chemical solutions or emulsions.

4.6 Characteristics of the Chemical Materials Used

Table 4.3 illustrates the chemical materials used in this study, their forms and illustration formulae. Chemical characteristics are as follows:

1. Polyvinyl Alcohol (PVA1 and PVA2):

Both polyvinyl alcohols PVA1 and PVA2 used in this study were produced by BDH limited, Broom Road, Poole, BH12 4NN, England*. Their molecular weights were approximately 14000 and 125000, respectively. The viscosity of 4% aqueous solution of each PVA1 and PVA2 chemicals at 20°C were 4 - 6 cP and

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* *Trade names and company names are included for the benefit of the reader and do not imply endoresment or preferential treatment of the product by the University of Durham.*

Table 4.3 : Chemical Materials Used, Their Forms, Illustration Formulas and the Trade Names

Chemicals	Abbr.	Form	Illustration formulae	Trade name
Polyvinyl alcohol (M.Wt. 14,000)	PVA1	powder	[-CH2CH(OH)-]n	Polyvinyl alcohol 14,000
Polyvinyl alcohol (M.Wt. 125,000)	PVA2	powder	[-CH2CH(OH)-]n	Polyvinyl alcohol 125,000
Polyethylene glycol (M.Wt. 4000)	PEG3	powder	CH2OH(CH2OCH2)nCH2OH	Polyethylene glycol 4000
Polyethylene glycol (M.Wt. 400)	PEG4	liquid	CH2OH(CH2OCH2)nCH2OH	Polyethylene glycol 400
Bitumen emulsion	B.E.	liquid		Bitumen emulsion A1-55
Ferquatac emulsion (resin)	F.E.	liquid		Ferquatac RB-50
Vinamul	V1	liquid		Vinamul 3270
Vinamul	V2	liquid		Vinamul 3277
Vinamul	V3	liquid		Vinamul 18207
Aquapol1 (resin)	Aq1	liquid		Aquapol 35-0019
Aquapol2 (resin)	Aq2	liquid		Aquapol 35-0031

35 - 50 cP, while the maximum ash percentages were 1% and 0.75%, respectively. A known weight of each polyvinyl alcohol was dissolved in distilled water, heated to 80 - 90^{o}C and stirred continuously, and then made up to an exact volume with distilled water. These concentrated solutions were later diluted with distilled water to provide the concentrations used in the tests.

2. Polyethylene Glycol (PEG3 and PEG4):

Both polyethylene glycols PEG3 and PEG4 used in this study were produced by A and J Beveridge Limited, Derwenthangh Industrial Estate, Swalwell, Newcastle upon Tyne NE16 3BJ, England*. Their molecular weights were approximatly 4000 and 400, respectively. PEG4 was already a solution with density of 1.13 gm cm^{-3}, while PEG3 was crystals. As in the case of PVA, a known weight of PEG3 was dissolved in distilled water, heated to 80 - 90^{o}C and stirred continuously, and then made up to an exact volume with distilled water. Test solutions were made by dilution of these concentrated solutions.

3. Vinamul 3270; 3277 and 18207 (V1; V2 and V3):

All these three products are water based synthetic resin dispersions (vinyl acetate-ethylene copolymer with different stabilizing systems), produced by Vinamul Limited, Mill Lane, Carshalton, Surrey SM5 2JU, England*. The active concentration of each is approximately 55%.

4. Bitumen Emulsion A1-55 (B.E.):

Bitumen emulsions consist of small droplets of bitumen dispersed in water and may be either anionic or cationic depending on the chemicals used to emulsify the bitumen. When bitumen emulsion is applied to the surface of the soil, the water evaporates, and the emulsion changes colour from brown to black. Anionic bitumen emulsion (A1-55) is produced by Ayton Asphalte Co. Ltd., Browick Works, Wymondham, Norfolk, England*. The concentration of the active bitumen in this product is 55%. Bitumen emulsion at a rate of 0.7 l $m^{-2}$was recommended by the Ayton Company for grass growing and against wind erosion.

5. Ferquatac Emulsion RB50 (F.E.):

Ferquatac emulsion RB50 is a 50% resin solids, solvent-free aqueous disper-

sion of plasticing resin Fergatac RB. It is produced by Ferguson and Menzies Ltd., 312 Broomloan Road, Glasgow G51 2JW, Scotland*. The pH of the emulsion is 8.5 - 11.0, the appearance is light brown to opaque, and the particle size is 1 - 3 microns. Ferquatac emulsion RB50 was diluted with water to provide the concentrations used in this study project of sand dune stabilization.

6. Aquapol 35-0019 (Aq1):

Aquapol 35-0019 is a water gellant polyurethane prepolymer resin produced by Freeman Chemicals Limited, Polymer Division, P.O.Box 8, Ellesmere Port, South Wirral L65 0HB, England*. Its ingredients by weight are Diisocyanate Prepolymer > 99% and Toluene Diisocyanate < 1%, the density is 1.14 gm cm^{-3}, the chemical reacts with water, the conditions to avoid are water and temperatures above 50°C or below 0°C. After mixing the Aquapol with water for 20 - 30 seconds, the mixture must be immediately applied onto the sand to impregnate the sand before gelling. Gel time at 20°C is approximately one minute. This can be extended to approximately two minutes if the water is chilled to 5°C.

7. Aquapol 35-0031 (Aq2):

Aquapol 35-0031 is another water gellant polyurethane prepolymer resin produced by Freeman Chemicals limited. Its gradients by weight are Diisocyanate Prepolymer > 99% and Isophorone Diisocyanate < 1%, the density is 1.08 gm cm^{-3}, the chemical reacts with water, the conditions to avoid are again water and temperatures above 50°C or below 0°C. Owing to the less reactive nature of Aquapol 35-0031, a catalyst (S220/9) is required which can be pre-mixed with the water prior to mixing with the Aquapol. S220/9 is a Triethanolamine chemical product. The recommended concentration from S220/9 in water by Freeman is 0.5% - 0.6% by weight. Gel time for the Aquapol 35-0031 with the mixture of water and the catalyst S220/9 at 20°C is approximately 20 minutes.

4.7 Experimental Methods

4.7.1 Chemical Materials Tests

In this study project, laboratory, greenhouse and field tests were conducted on sand samples from Druridge Bay and Baiji sand dunes. The aims were, firstly to determine the effects of the selected soil stabilizers ie. PVA1; PVA2; PEG3; PEG4; V1; V2; V3; F.E.; B.E.; Aq1 and Aq2 (table 4.2), on selected physical properties of the sands as follows: infiltration rate, hydraulic conductivity, aggregate stability, modulus of rupture, sand temperature, evaporation rate and rate of erosion both by wind and water. Secondly, to assess the effect of the selected chemicals on the growth and germination of marram grass, rye grass and *Panicum spp.* seeds, the growth of marram grass and lyme grass tillers, and young *Eucalyptus spp.* and *Acacia spp.* plants. The reasoning behind the selection of these tests is as follows:-

1. Infiltration rate and hydraulic conductivity are parameters commonly used in evaluating soil infiltration characteristics and their ability to transmit water. In doing this they influence the degree of water runoff and hence soil surface erosion, and also the soil-water content and thus the success of seed germination and plant growth.
2. The stability of aggregates, both dry and wet, are good measures of the capability of the soil surface to resist wind and water erosion. The larger the aggregates, the more stable is the surface layer. Furthermore, soil aggregation is also a very important factor in controlling porosity, air-water interrelationships, and hence the distribution of plant root systems.
3. The modulus of rupture is an index to evaluate the hardness of the soil surface crust. Which in turn influences the surfaces susceptibility to wind and water erosion, and the emergence of the newly germinated seedlings.
4. Soil temperature affects soil-water evaporation, microbial activity, chemical reaction rates, and the germination of seeds. Mulched soils can increase seed

germination percentages in the early stages of cultivation.

5. Water evaporation is a measure of water loss from the soil surface. Surface mulch, especially in arid and semi arid zones, can be an important factor for seed germination and plant growth as it reduces soil moisture loss by evaporation.
6. Even though the chemicals may show promise in each of the previous tests, the critical test for the chemicals is their ability to withstand both wind and water erosion. Thus these were tested in windtunnel and simulated rainfall experiments.
7. Investigation of the seed germination and plant growth under the effect of the various chemicals used attempted to discover:

a. The survivability of young *Eucalyptus spp.* and *Acacia spp.* plants, and marram grass and lyme grass tillers in Druridge Bay dune sand samples mulched with the various stabilizers.

b. The capability of newly germinated seedlings of marram grass, rye grass, and *Panicum spp.* to penetrate the mulched surface layer of Druridge Bay and Baiji sand samples.

c. To asses the toxic effects if any, of the various chemical materials on the germination of seeds and the growth of different plants species.

d. The best combination of chemical and botanical methods for sand dune stabilization.

4.7.2 Characteristics of the Dune Sands Used in This Study

Table 4.4 illustrates some physical and chemical characteristics of air-dry sand samples of Druridge Bay sand dunes:-

In this study, the analytical methods employed are mainly those used by the United States Salinity Laboratory Staff (Richards, 1969). These are as following:

1. All soluble ions were measured from 1:1 soil:water ratio extracts:

Table 4.4 : Some Chemical and Physical Characteristics of Druridge Bay Sand Dunes.

Character	Druridge Sands
EC (mmhos cm^{-1})	0.188
pH	7.2
Alkaline-Earth Carbonates (%)	6.37
Gypsum (meq per 100 gm soil)	0.99
Organic Matter (%)	0.83
Sand (Coarse; Medium and Fine) (%)	0.3; 84.6; 14.5
Silt (Coarse; Medium and Fine) (%)	0.3; 0.1; 0.1
Clay (%)	0.1
Texture	Sandy
C.E.C. (meq per 100 gms soil)	0.71
Soluble Ions (meq per 100 gms soil)	
Na^{+}	0.037
K^{+}	0.011
Ca^{++}	0.127
Mg^{++}	0.017
Cl^{-}	0.042
$CO3^{--}$	0.000
$HCO3^{-}$	0.105
Total N (%)	0.019
Available P (mgm per 100 gm soil)	0.396
S.A.R.* (meq $l^{-1/2}$)	0.436
Exchangeable Cations (meq per 100 gms soil)	
Na^{+}	0.103
K^{+}	0.069
$Ca^{++} + Mg^{++}$	0.538
E.S.P.** (%)	14.507
Bulk Density (gm cm^{-3})	1.52
Sand Particles Density (gm cm^{-3})	2.64
Porosity (%)	42.00

* S.A.R. (Sodium Adsorption Ratio) = $Na^{+} / [(Ca^{++} + Mg^{++}) / 2]^{-1/2}$

Na^{+} ; Ca^{++} ; Mg^{++} = Soluble Cations (meq l^{-1})

** E.S.P. (Exchangeable Sodium Percent) = (Na^{+} / C.E.C.) x 100%

Na^{+} = Exchangeable Sodium (meq / 100 gm soil)

C.E.C. = Cation Exchange Capacity (meq / 100 gm soil)

a. Na^{+} ; K^{+} ; Ca^{++} and Mg^{++} by using the Atomic Absorption spectrophotometer - Perkin Elmer 5000, Automatic Burner Control.

b. $CO3^{--}$ and $HCO3^{-}$ by titration with 0.01 N H2SO4 and using 0.1% phenolphthalein and 0.01% methyl orange indicators.

c. Cl^{-} by titration with standard solution of mercuric nitrate and using a mixed indicator solution.

d. Total nitrogen content was measured using a modified technique devised by Kjeldahl in 1883, in which the organic matter is oxidised to release the nitrogen it contains as ammonia.

d. Available phosphorus was measured by Olsen's method.

2. Electrical Conductivity and pH measurements for the 1:1 soil:water ratio extracts were measured using a Conductivity Measuring Bridge (MC1 MK.IV / Electronic Switchgear - London - Ltd.) and glass electrode pH Meter (7020 / Electronic Instruments Ltd.) respectively.

3. Cation Exchange Capacity (C.E.C.) was measured by saturating the soil sample with sodium ions using (1 N) sodium acetate, and then extracting the exchangeable sodium ions by the mean of (1 N) ammonium acetate. The Atomic Absorption Spectrophotometer was used for the measurement of the extractable sodium.

4. Alkaline - Earth Carbonates were measured by gravimetric loss of carbon dioxide, using hydrochloric acid.

5. Gypsum was measured by the quantitaive precipitation with, acetone.

6. Organic carbon by a modified Walkley and Black method (Jackson, 1958).

7. Exchangeable sodium and potasium were measured using the above mentioned Atomic Absorption Spectrophotometer after centrifuge extraction by means of ammonium acetate solution (1 N).

8. Exchangeable calcium and magnesium were measured through the differences between the cation exchange capacity of each sand sample and the total

exchangeable sodium and potasium ions of that sample.

9. Particle size analysis by the sieve and pipette method.
10. Bulk density and sand particles density were determined on air-dry samples using 100 ml Pycnometers.
11. The Porosity was calculated from the formula:

    $n = (dp - db) / dp$

    n = porosity (%); dp and db = sand particle and bulk densities, respectively.

4.7.3 Growing of Eucalyptus and Acacia Young Plants

Seeds of *Eucalyptus microtheca* and *Acacia cyanophylla* from Iraq, were planted in soil compost in small plastic trays in the greenhouse (max. temperature was = 25°C, and the min. temperature was = 21°C), and irrigated every two days, this irrigation regime continued for two weeks after seedling emergence. Two weeks after emergence, the seedlings were transferred to pots containing about 1 kg of soil compost, only one plant was put in each pot. The young plants were then irrigated twice a week and grown on for use in experiments involving the various stabilizers. Photo 4.1 show young plants of *Eucalyptus spp.* and *Acacia spp.* (8 months old) before being used in chemicals experiments.

4.7.4 Application of the Chemical Stabilizers to the Sand Surface

In all the laboratory, windtunnel and greenhouse tests the chemical mulches were made up to the specified concentrations using distilled water, whilst in the field local tap water was used. Air-dry sand was used in all the laboratory trials, whilst in the greenhouse the chemicals were applied to samples at field capacity and in the field to sand of varying moisture content (4 - 6% on an air-dry basis). With the large pots of the greenhouse experiments, and the field plot tests, a Falcon 10 litre sprayer (Cooper, Pegler and Co. Ltd., Burgess Hill, Sussex RH15 9LA, England) was used for the application of all chemicals with the exception

Plate 4.1: *Eucalyptus microtheca* **and** *Acacia cyanophyla* **Plants (8 Months Old).**

of Aquapol1 and Aquapol2, which because of their short gelating time (1 minute and 20 minutes, respectively), were applied by pouring the solutions onto the sand surface. Both Aquapols were applied to the sand surface using a watering can of about 6 litres capacity. Photos 4.2 and 4.3 show the two above mentioned methods of chemicals application.

Plate 4.2: Method Used for Spraying Chemical Stabilizers.

Plate 4.3: Method Used for Applying Aq1 and Aq2 Chemical Stabilizers.

CHAPTER 5

EFFECT OF SELECTED CHEMICAL STABILIZERS ON SOIL PROPERTIES AND PLANTS GROWTH - LABORATORY AND GREENHOUSE EXPERIMENTS

5.1 Effect of Soil Chemical Stabilizers on Soil Physical Properties

5.1.1 Introduction

Soil physical properties widely influence plant growth. Important physical properties include moisture content, aeration, temperature, mechanical and physico-chemical properties. Any change in soil surface properties will affect the above factors. For example, the application of bitumen emulsions to the soil as surface mulches can increase soil temperature (Saleh, 1984), and the stability of soil aggregates (Hartmann et al., 1975); and can decrease both infiltration rate and hydraulic conductivity (Gabriels and De Boodt, 1975; and De La Pena and Gabriels, 1976), and water evaporation (Lenvain and De Boodt, 1976; and Gabriels et al., 1978).

Synthetic soil conditioners can improve soil physical conditions in a short time and many investigators have studied the effect of polyvinyl alcohols (PVA), polyethylene glycols (PEG), polyacrylamide (PAM) and bitumen emulsions as surface mulches on the stability of soil structure aggregates, for example (Chepil, 1955; Varnavskaya et al., 1967; Gabriels and De Boodt, 1974; Gabriels, 1975; Gabriels et al., 1975b; Szczypa et al., 1976; Janpeisov et al., 1976; Kachinsky and Mosolova, 1976; and Tayel and Anter, 1978). Of particular importance are the use of many chemicals with large molecular weights, for example, polyethylene glycol, polyvinyl alcohol and polyvinyl acetate. Since as the molecular weight increases, the amount of chemical required to achieve a comparable extent of aggregation

decreases (Ueda and Harada, 1968; and Carr and Greenland, 1972).

Many other studies have individually investigated the effects of bituminous emulsions and other synthetic conditioners on soil temperature and soil hydrophysical properties (Kowsar et al, 1969; Gabriels and De Boodt, 1974; 1975; Tayel and Anter, 1978; Callebaut and De Boodt, 1981; and Tayel et al., 1981b).

The succeeding sections describe the techniques used and results obtained from testing the effects of the selected chemicals on the following physical properties of Druridge Bay sand: infiltration rate, hydraulic conductivity, sand temperature, evaporation rate and aggregate stability.

5.1.2. Effect of Soil Chemical Stabilizers on the Movement of Water Through Soils

5.1.2.1 Theoretical Basis

Horton (1933) introduced the concept of infiltration in the hydrologic cycle and defined infiltration capacity as "the maximum rate at which a given soil can absorb precipitation in a given condition". Accumulated Infiltration, also called Cumulative Infiltration, is the total quantity of water that enters the soil in a given time. The relationship between accumulated infiltration and elapsed time are usually expressed by the following empirical equation (Michael, 1978):

$$Y = at^{\alpha} + b \qquad t \neq 0 \tag{1}$$

in which

Y = accumulated infiltration in time t, (cm)

t = elapsed time or infiltration opportunity time (min)

and a, α, b = constants

Michael (1978) indicated that, field experimental data on accumulated infiltration versus time, when plotted on an ordinary co-ordinate paper, give a

parabolic curve. When the data are plotted on a log-log paper a linear relationship is indicated.

The infiltration rate at any time (t) is obtained by differentiating equation (1) as follows:

$$Y = at^{\alpha} + b$$
$$\frac{dY}{dt} = a\alpha t^{\alpha-1} \tag{2}$$

$\frac{dY}{dt}$ is the instantaneous infiltration at any elapsed time.

Two other important parameters influencing water movement in the soil are, permeability and hydraulic conductivity, these are measures of the ability of soil to conduct water. Klute (1965) illustrated the relationship between both intrinsic permeability and hydraulic conductivity of the soil through the following equation:

$$K'_w = \frac{\eta}{\rho_w g} K = \frac{\eta}{\rho_w g} \frac{VL}{A\Delta h \Delta t} \tag{3}$$

in which

K'_w = intrinsic permeability with water, (cm^2),

K = hydraulic conductivity, (cm sec^{-1}),

V = volume of percolate in time t, (cm^3),

L = length of soil column, (cm),

Δh = difference in hydraulic head between the inflow and outflow ends of the soil column, (cm),

A = cross sectional area of the soil column, (cm^2),

Δt = time interval for volume of percolate (V) to pass through the soil, (sec),

η = viscocity of water at the recorded temperature, (dyne sec cm^{-2}) or (poises),

ρ_w = density of water, (gm cm^{-3}),

g = acceleration of gravity, (cm sec^{-2}),

η, ρ_w and g = constants

Infiltration rate, accumulated infiltration, hydraulic conductivity and intrinsic permeability are parameters commonly used in evaluating soil infiltration characteristics and their abilities to transmit water. The movement of water through soil can be greatly influenced by factors such as condition of the soil surface (Duly, 1939; Frenkel et al., 1978; Morin et al., 1981; and Helalia et al., 1988), salt concentration of the water together with its sodium level (Quirk and Schofield, 1955; Das and Dakshinamurti, 1975; Frenkel et al., 1978; Pupisky and Shainberg, 1979; Oster and Schroer, 1979; Shainberg and Letey, 1984; Kazman et al., 1983; Agassi et al., 1985; Miller and Baharuddin, 1986; Ben-Hur et al., 1987; and Chiang et al., 1987), gypsum content (Loveday, 1974; Keren and Shainberg, 1981; Miller, 1988; and Miller and Scifers, 1988), the initial moisture content and incapsulation of the air within the soil during infiltration (Constantz et al., 1988), vegetation cover (Michael, 1978), and many other factors including soil texture, structure, porosity, degree of swelling of soil colloids and organic matter, duration of irrigation or rainfall and viscosity of water (Michael, 1978; and Ayers and Westcot, 1985). Any change in any of these influencing factors will thus affect both infiltration rate and hydraulic conductivity of the soil. Therefore, the use of soil stabilizers as mulches on soil is likely to have a considerable impact on the infiltration rate and its hydraulic conductivity.

The applications of soil chemical conditioners as surface mulches, could either increase or decrease both infiltration rate and hydraulic conductivity of the soil. The increase or decrease in both properties depends on soil conditions, chemicals used and their applied concentrations (Bower and Hanks, 1961; Gabriels, 1972; Gabriels and De Boodt, 1975; Carr and Greenland, 1975; and Tayel et al., 1981b). In many studies, applications of chemical materials have been found to increase soil infiltration rate and hydraulic conductivity (Rabines Flores, 1972; 1973; Carr and Greenland, 1975; and Verplancke et al., 1976). For example, on the alluvial area on the West Coast of Peru there was an urgent problem related to reclamation

of salt-affected soils. Although water of good quality was available, a problem remained of how to leach the soil when its infiltration rate was low due to the swelling of clay particles in the presence of sodium salts. A surface treatment with bituminous emulsion, at a concentration of 1.5% increased the infiltration rate of the soils by a factor of 3 (Rabines Flores, 1973).

Carr and Greenland (1975) found that treatment of simulated sodic and natural sandy loam soil with polyvinyl acetate (PVAc) emulsions (0.03% to 0.12% by weight) produced faster infiltration rates as a result of the increased in soil surface stabilization against slaking and dispersion.

Verplancke et al. (1976) observed that treatment of a silt loam soil with polyacrylamide (PAM) and polyvinyl alcohol (PVA) increased the infiltration rate and the corresponding diffusivity values*, while both chemicals reduced the soil-water diffusivity when added to a loamy sand and a dune sand soil. The effect of the two chemicals on water diffusivity through soils depends, to a large extent, on the texture of the soil.

Cook and Nelson (1986) found that polyacrylamide (PAM) solutions applied to the surface of properly prepared seedbeds in crust forming soils, significantly reduced aggregate breakdown and soil crust formation, thereby maintaining good infiltration and aeration characteristics.

In a study of the application of the cationic polymer Guar Product (CP-14) to three soils at concentrations of (0, 5, 10, 20 and 50 mg l^{-1}) of the chemical in synthesized canal water and well water applied to the soil in a rainfall simulator experiment. Helalia and Letey (1988) and Helalia et al. (1988) found that, with one exception, the infiltration rate increased as the polymer concentration

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* $D_Q = -\frac{1}{2}\frac{d\lambda}{d_Q}\int_{Q_i}^{Q_s}\lambda d_Q$ *Where* D_Q *is the soil-water diffusivity at the volumetric moisture content* Q, Q_i *and* Q_s *are the initial moisture content and the moisture content at saturation respectively, and* λ *is transformation factor.*

increased for all soils and both waters. The highest incremental effect was between 0 mg l^{-1} and 5 mg l^{-1} polymer.

In three from four saline soils treated with 15 ml Humofina B2864 diluted in 45 ml of water per 1 kg soil, it was found that the hydraulic conductivity increased 7 - 9 times for the samples treated with a bituminous emulsion as compared to untreated soil (Rabines Flores, 1972). In the fourth soil the increase was two times because of the low clay content and a high salt content.

Gabriels (1972) found that artificial stabilization with 0.15% polyvinyl alcohol (PVA) or with 1.5% bitumen emulsion of a loamy soil aggregates (both stabilizers on the base of air-dry soil weight), kept the hydraulic conductivity and the outflow high and the water retaining capacity low.

Pla (1975) illustrated that in soils of six different textures, those treated with 0.16% PAM and 1.25% bituminous emulsion (on dry soil basis) showed a much higher saturated hydraulic conductivity.

Tayel et al. (1981b) found that the hydraulic conductivity of calcareous and sandy loam soils treated with bituminous emulsion (0.25% - 2.0%), polyacrylamide (PAM) (0.05% - 0.2%) and polyvinyl acetate (PVAc) (0.125% - 1.5%) were at least 10 times that of the untreated soils.

Applications of some soil stabilizers to the soil surface produces a less permeable top layer. The effect of a less permeable surface layer on soil infiltration has been investigated in many studies (Childs and Bybordi, 1969; Edwards and Larson, 1970; and Hillel and Gardner, 1969; 1970). Hillel (1972) equated the act of a less permeable top layer as a bottleneck, it reduces water penetration into the soil, and causes infiltration into the underlying soil to happen at a suction which normally results in unsaturated flow conditions.

De La Pena and Gabriels (1976) indicated that the addition of soil conditioners and mulches on very small aggregates, blocks the pores and prevents water infiltration. Asphalt emulsions, for example, because of their high contact angle

with soil particles, make the soil surface water repellent, and consequently reduce the infiltration rate.

In a rainfall simulator experiment using clods of a Clarion loam soil, Gabriels (1972) showed that the infiltration rate can be blocked not only by surface sealing by aggregate breakdown, but also by a high contact angle between bitumen emulsion and the treated small aggregates. The high contact angle was responsible for closing the small pores between the aggregates.

Gabriels and De Boodt (1975) demonstrated that the reduction in the infiltration rate of a sandy soil was due to the hydrophobic character of the bitumen treated sand surface.

In a silty clay loam, and fine sandy loam soils treated with various concentrations of dimethyl octadecyl ammonium chloride (DDAC) (0.05%, 0.10%, and 0.50% on the bases of soils weights), all treatments effectively reduced the amount and the rate of infiltration in the silty clay loam soil. In a fine sandy loam the 0.50% treatment reduced the infiltration by 96%; whilst the 0.05% and 0.10% treatments increased infiltration by 2% and 9%, respectively (Bowers and Hanks, 1961).

The applications of the hydrolysed starch polyacrylonitrile graft co-polymer "super gel" 0.05% - 0.2% to a sandy soil from Egypt decreased the hydraulic conductivity, intrinsic permeability and the mean diameter of soil pores (Tayel and El-Hady, 1981c).

Thus chemical mulches can have a variable effect on infiltration and conductivity rates of sandy soils depending on both the chemical structure of the stabilizer and the concentration used.

5.1.2.2 Techniques, Materials and Methods

This study was conducted using air-dry samples obtained from the surface 30 cm of Druridge Bay sand dunes. The chemical and physical characteristics of

the sand are illustrated in chapter 4 (table 4.4).

Having established the maximum concentrations of Aq1; Aq2 and F.E. that allowed infiltration (chapter 4 section 4.5), a series of comparative infiltration and hydraulic conductivity tests were established using the chemicals listed in (table 4.1) and at concentrations stated in (table 4.2). All chemicals were prepared or diluted with water to get the stated concentrations when applied at a rate of 6.0 l m^{-2}, and each treatment was tested in triplicate. The experiment involved adding these chemicals to 65 gm of air-dry sand in glass leaching columns of surface area 3.465 cm^2, these were then placed in a leaching rack and water added at the top (photo 5.1). Control samples using untreated Druridge Bay sand were included. Input and output water volumes as a function of time were measured. The input water data were later used for the calculation of the infiltration rates and accumulated infiltrations using the procedure described by Michael (1978). Saturated hydraulic conductivities and intrinsic permeabilities (Klute, 1965) of the sand, were calculated from the output data 10 minutes after the water first percolated through the leaching column. Ten minutes was more than adequate to ensure that the sand in the leaching tubes was completely saturated.

5.1.2.3 Results and Discussions

a. Effect of Soil Chemical Stabilizers on Infiltration Rate and Accumulated Infiltration of Druridge Bay Sand:

The effect of the chemical stabilizers PVA1; PVA2; PEG3; PEG4; V1; V2; V3; B.E.; F.E.; Aq1 and Aq2 on the infiltration rates of Druridge Bay sand are illustrated in figures (5.1 - 5.11). The effect of the chemicals on the accumulated infiltrations of the sands are shown in figures (5.12 - 5.22). In all cases, the figures represent the mean of 3 replicates.

The results indicate that with the application of PVA1; PVA2; PEG3; PEG4 both infiltration rate and accumulated infiltration increased when compared with

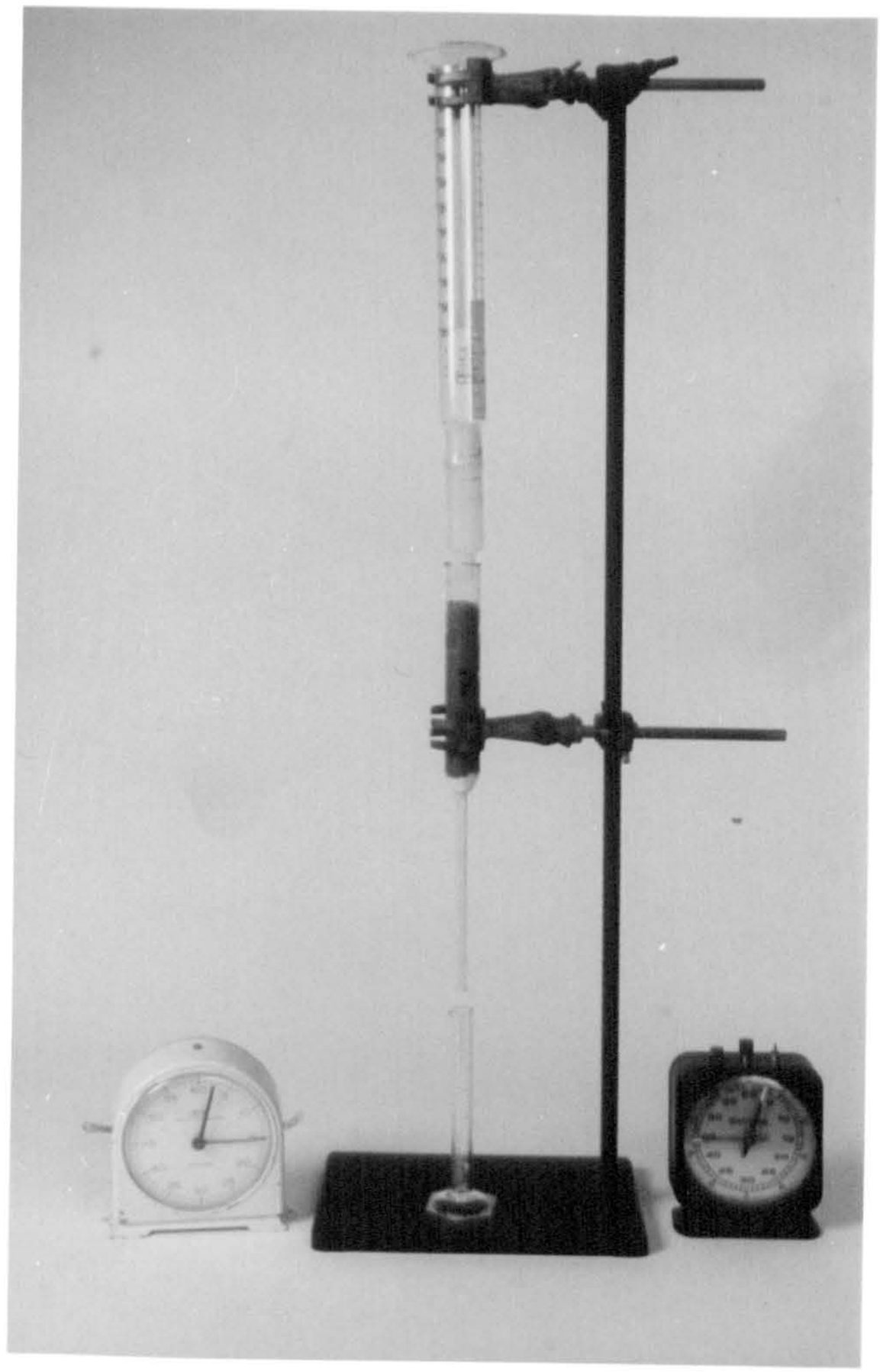


Plate 5.1: The Constant-Head System for Infiltration and Saturated Conductivity Measurements.

the control. Furthermore, the rate of increase was related to the concentration of the chemicals applied. The remaining chemical materials, V1; V2; V3; B.E.; F.E.; Aq1 and Aq2, reduced the infiltration rate and accumulated infiltration of the sand. In all these cases, increased chemical concentration caused a further decrease in infiltration. It is clear from all figures (5.1 - 5.22) that the increases or decreases in infiltration rates and accumulated infiltrations differ with various chemical materials. However, all the results were in excess of the minimum

Fig. 5.1: Effect of PVA1 on Infiltration Rate in Druridge Sands

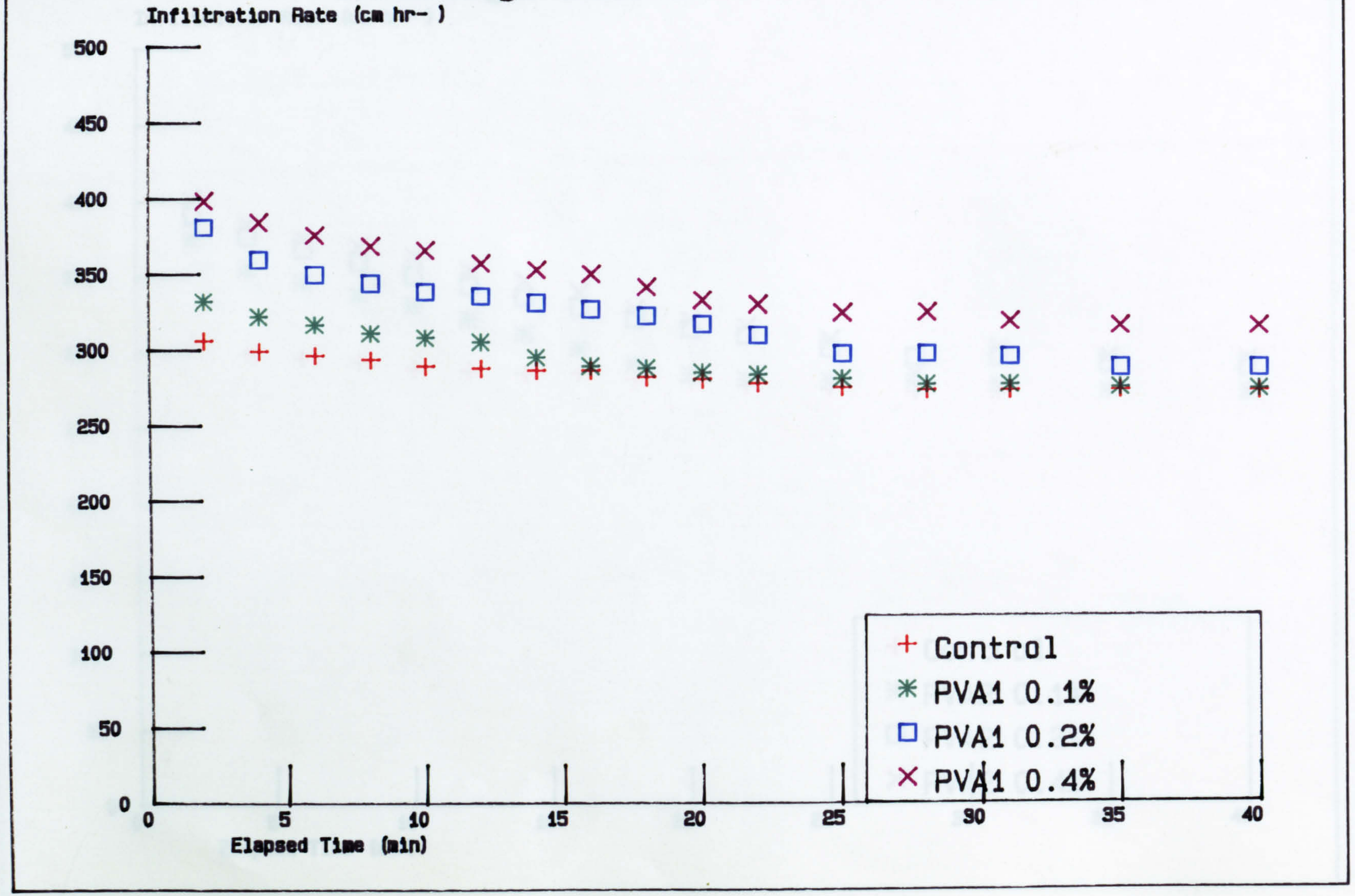


Fig. 5.2: Effect of PVA2 on Infiltration Rate in Druridge Sands

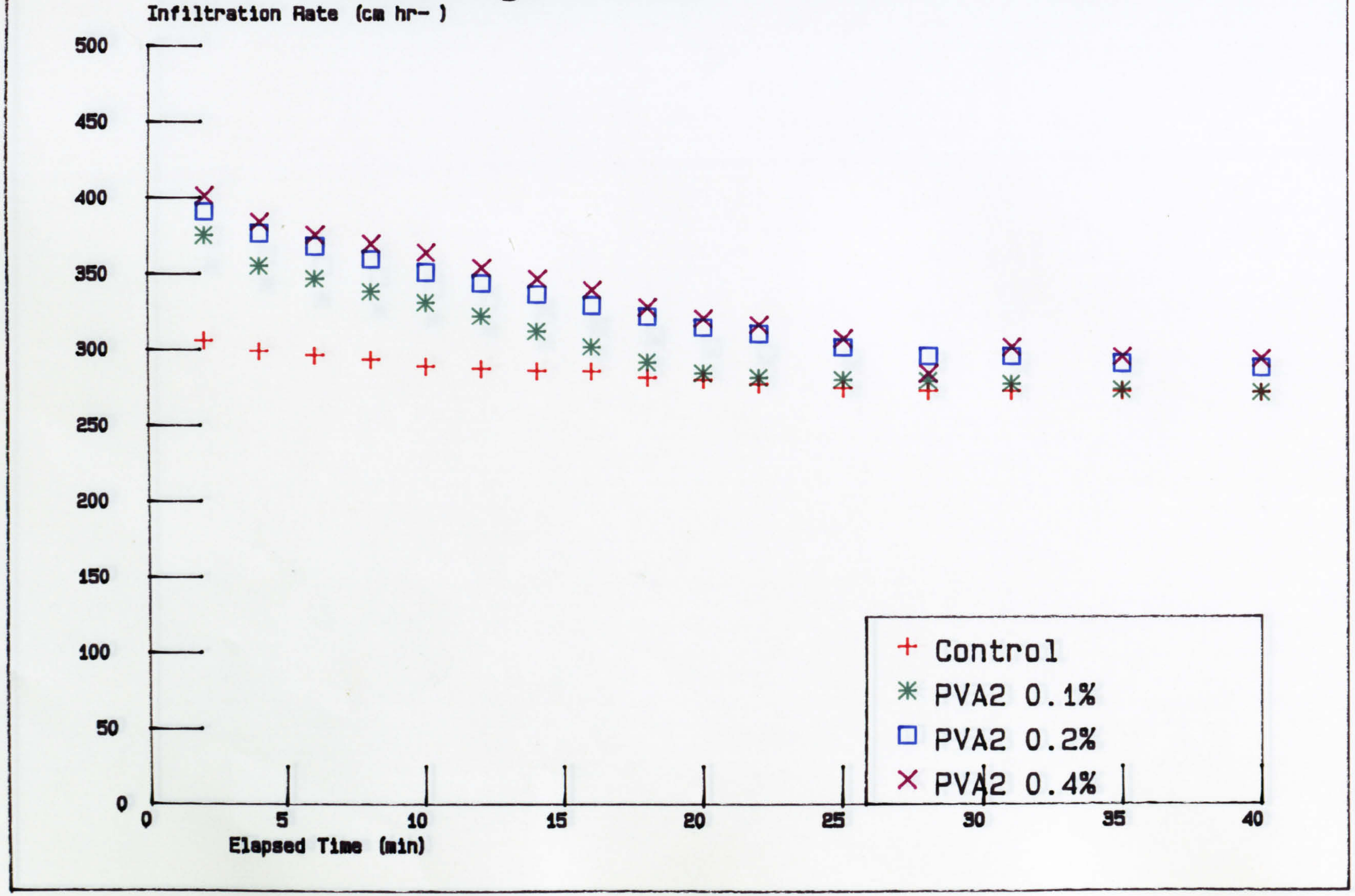


Fig. 5.3: Effect of PEG3 on infiltration Rate in Druridge Sands

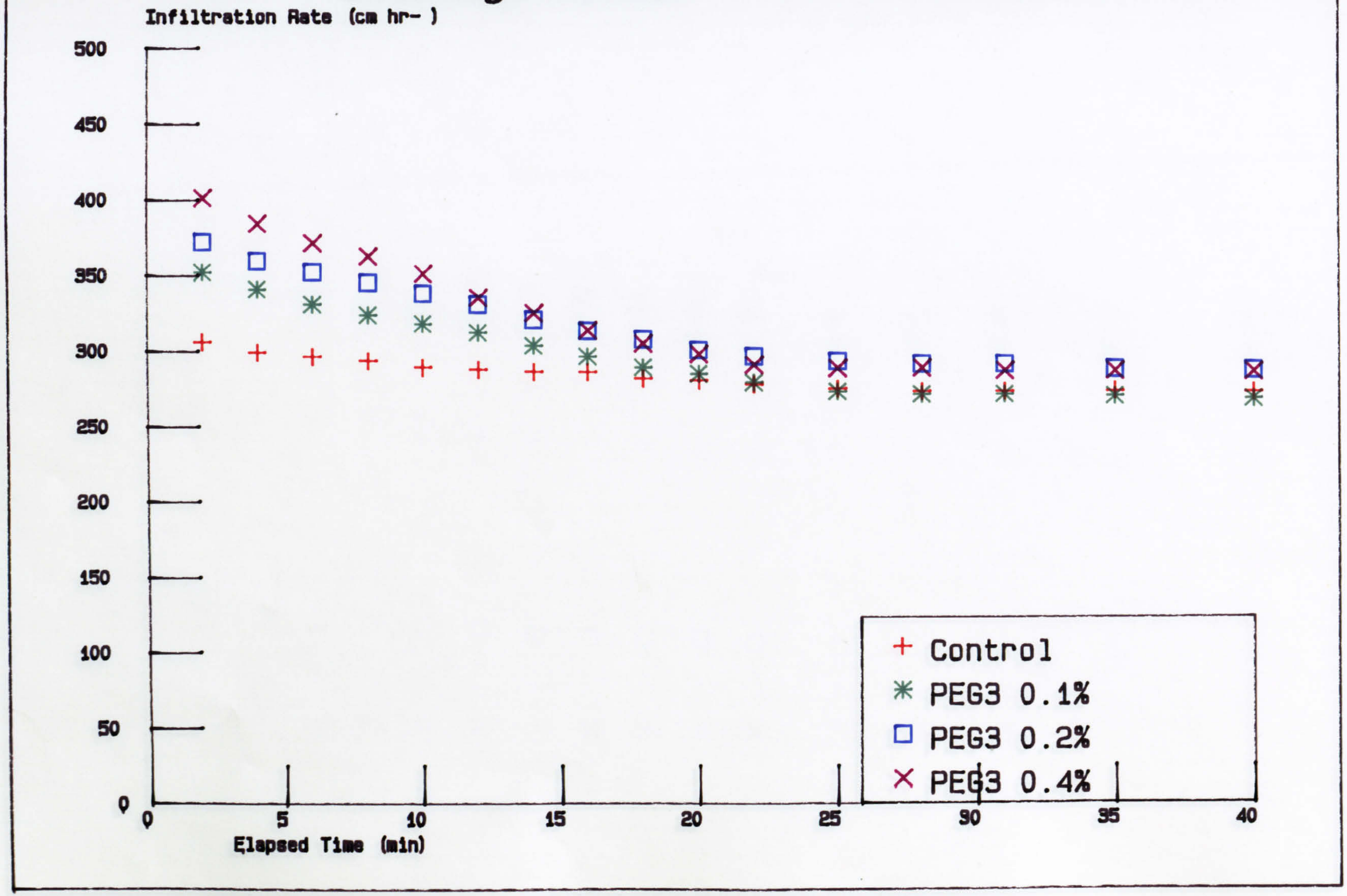


Fig. 5.4: Effect of PEG4 on Infiltration Rate in Druridge Sands

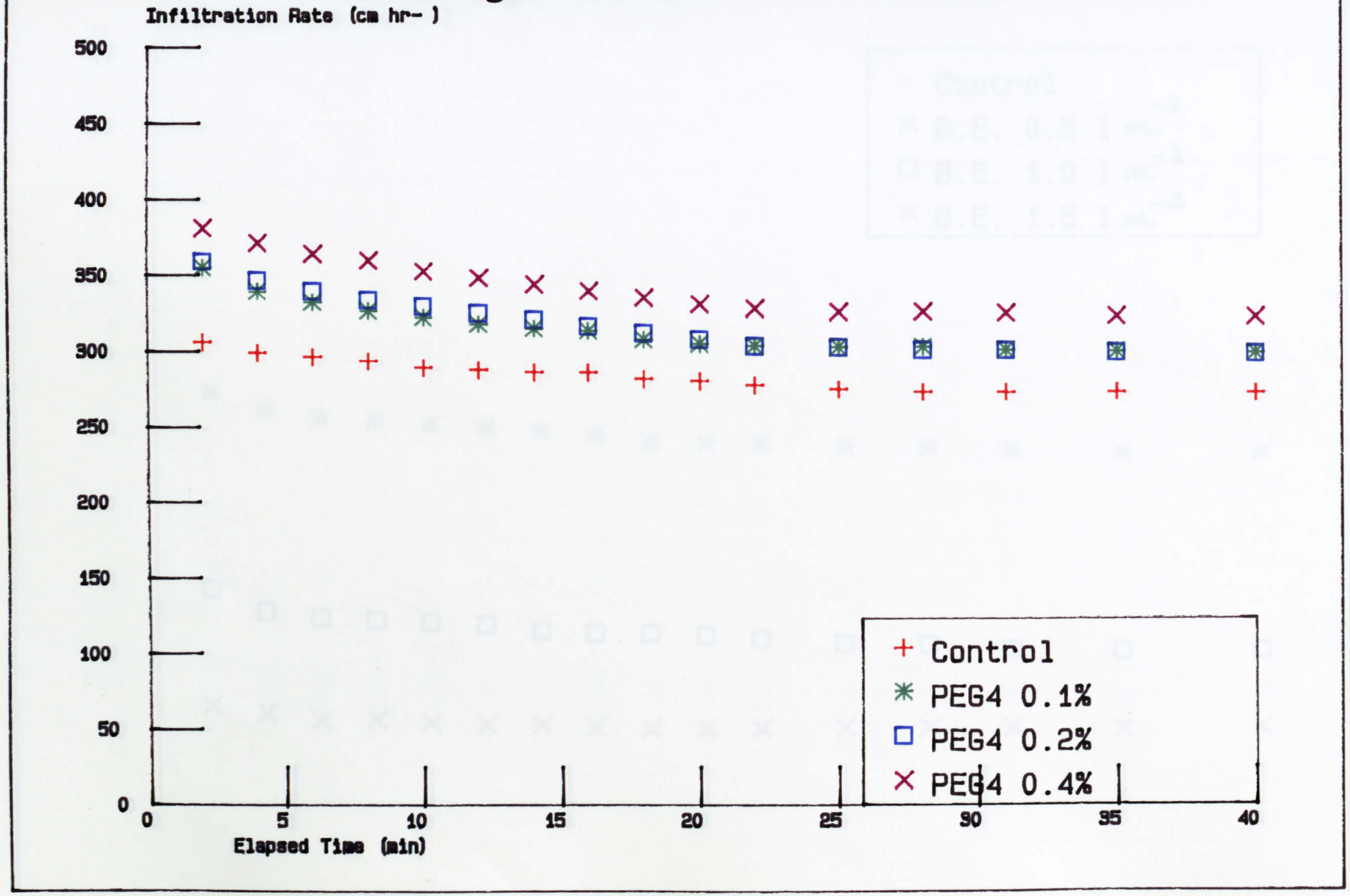


Fig. 5.5: Effect of B.E. on Infiltration Rate in Druridge Sands

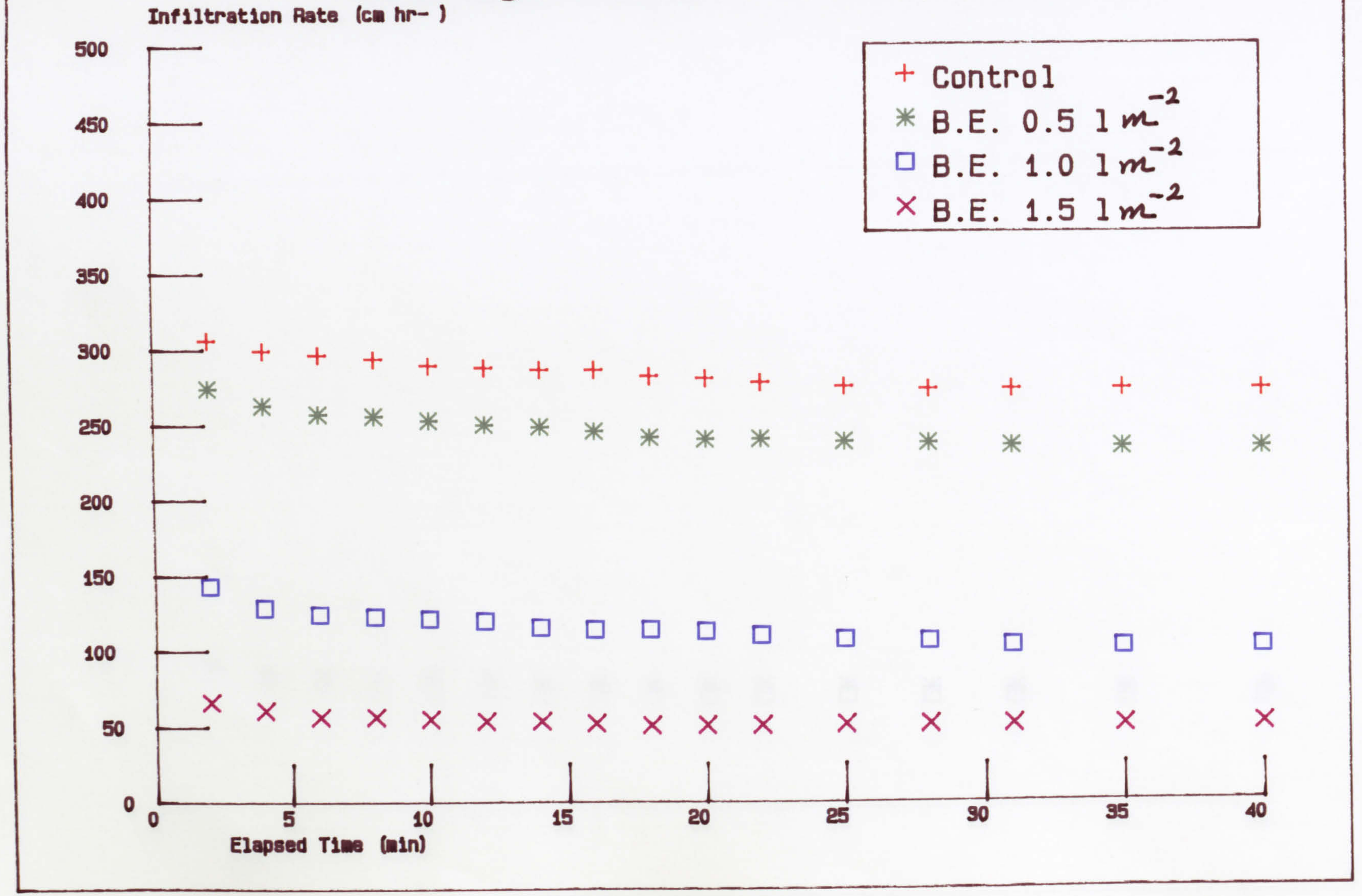


Fig. 5.6: Effect of F.E. on Infiltration Rate in Druridge Sands

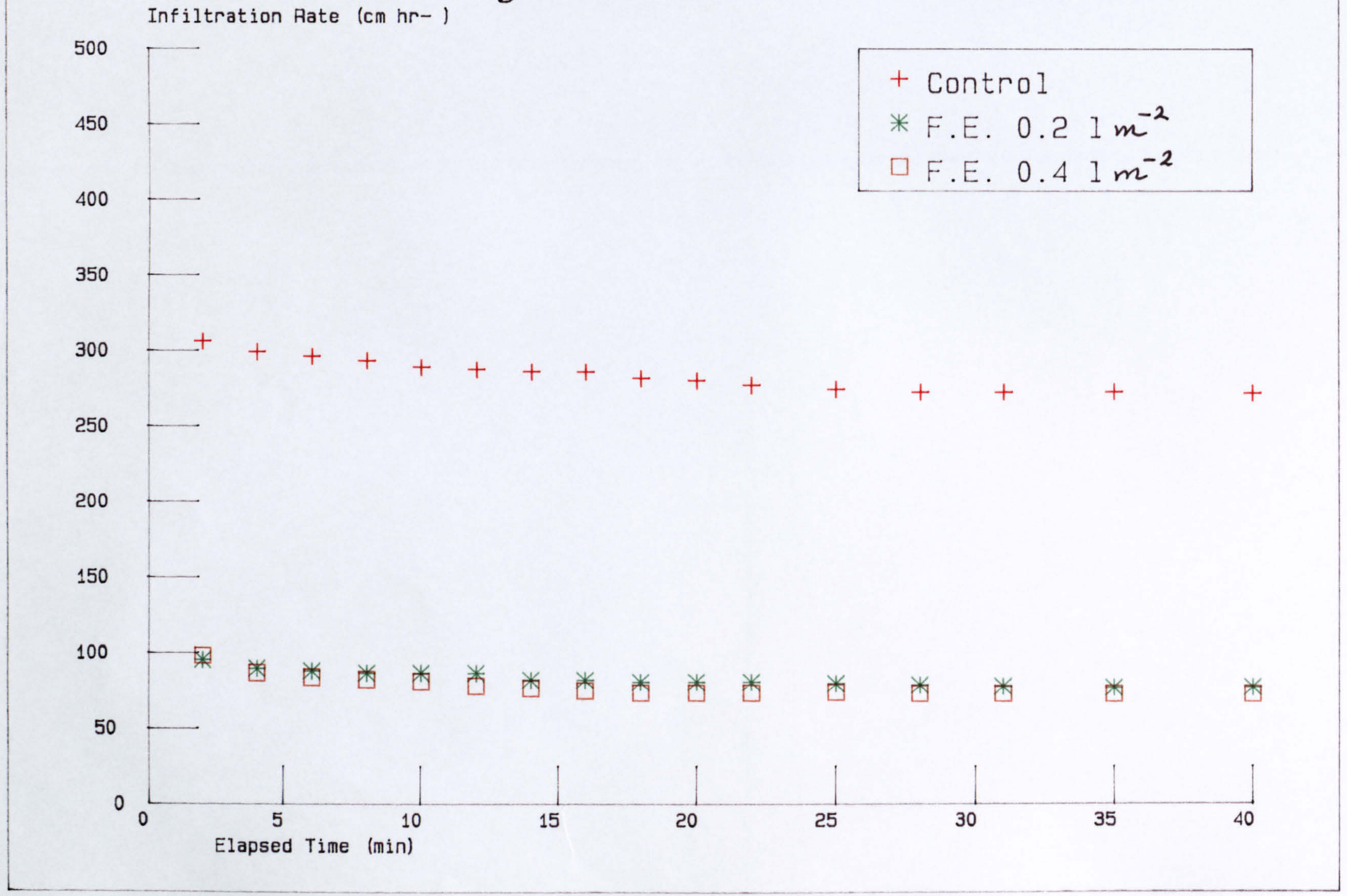


Fig. 5.7: Effect of V1 on Infiltration Rate in Druridge Sands

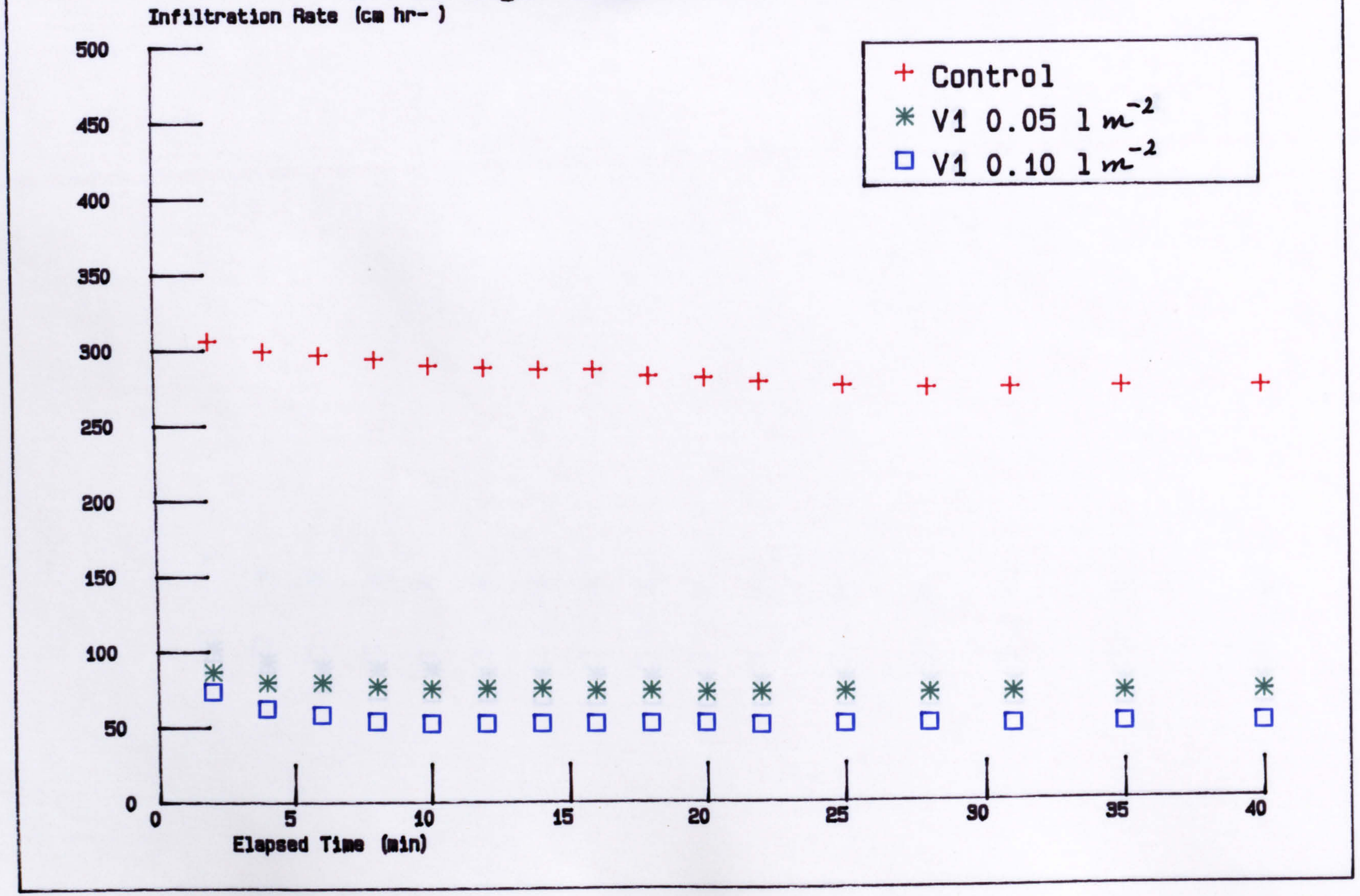


Fig. 5.8: Effect of V2 on Infiltration Rate in Druridge Sands

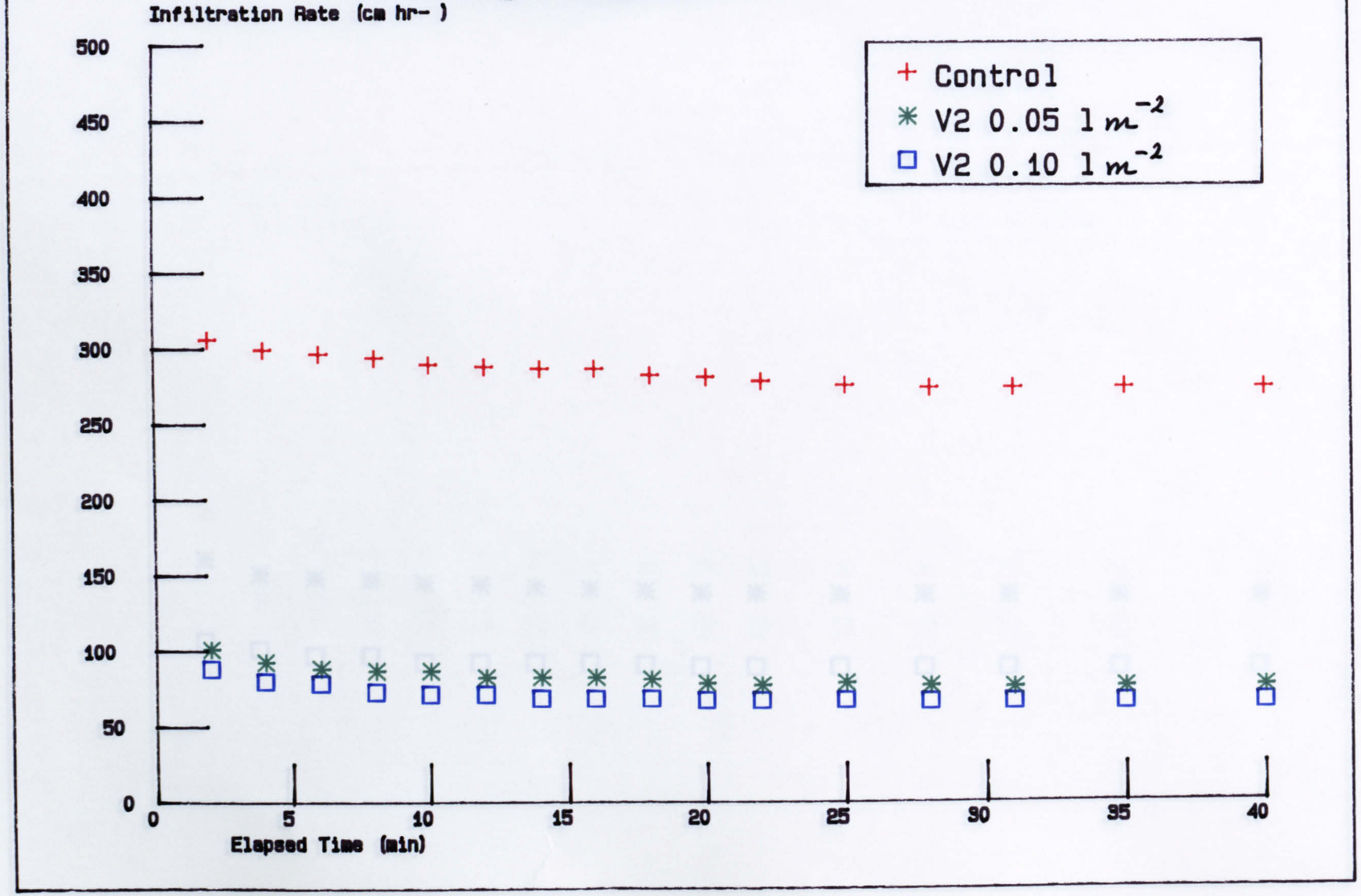


Fig. 5.9: Effect of V3 on Infiltration Rate in Druridge Sands

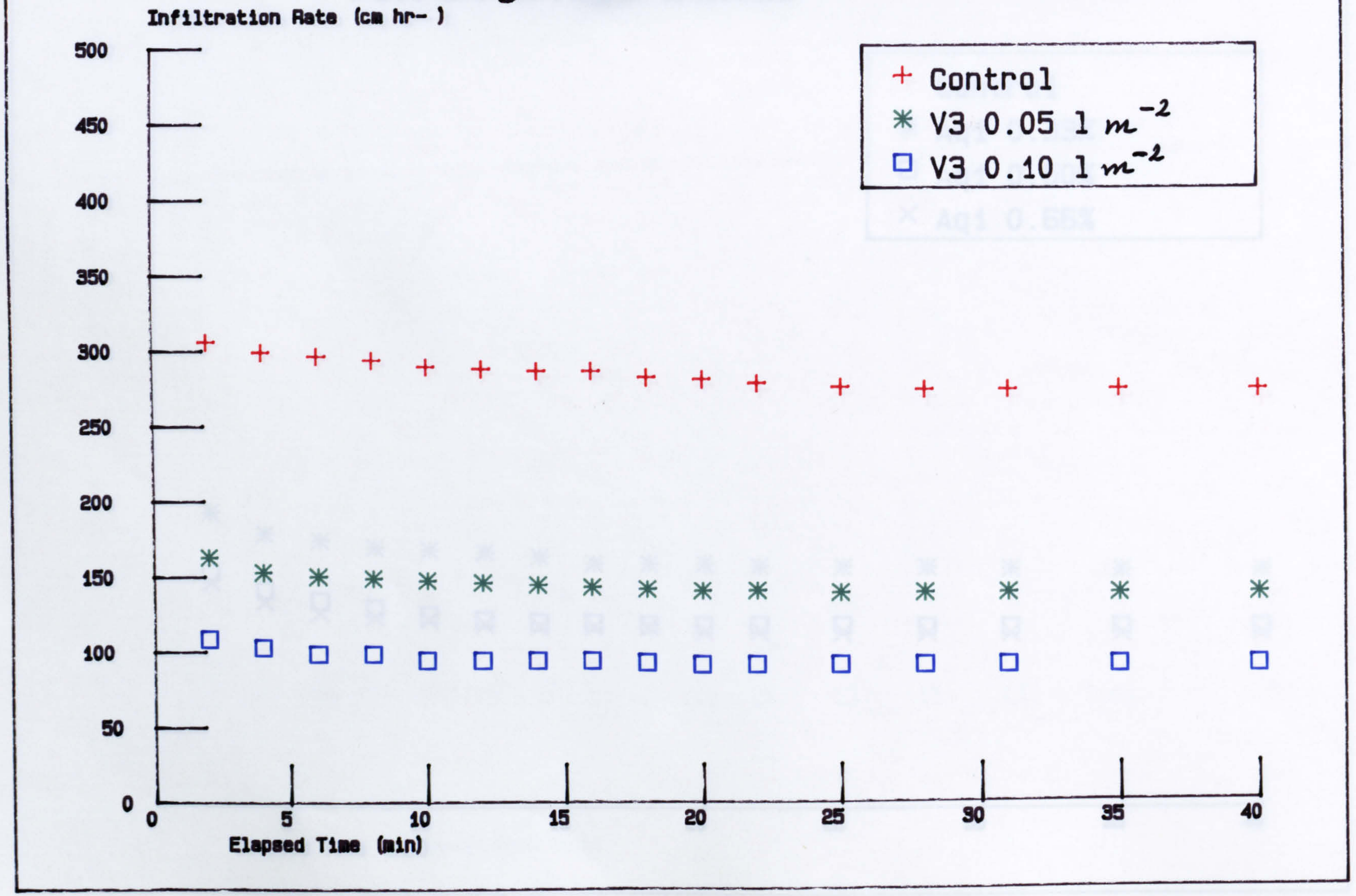


Fig. 5.10: Effect of Aq1 on Infiltration Rate In Druridge Sands

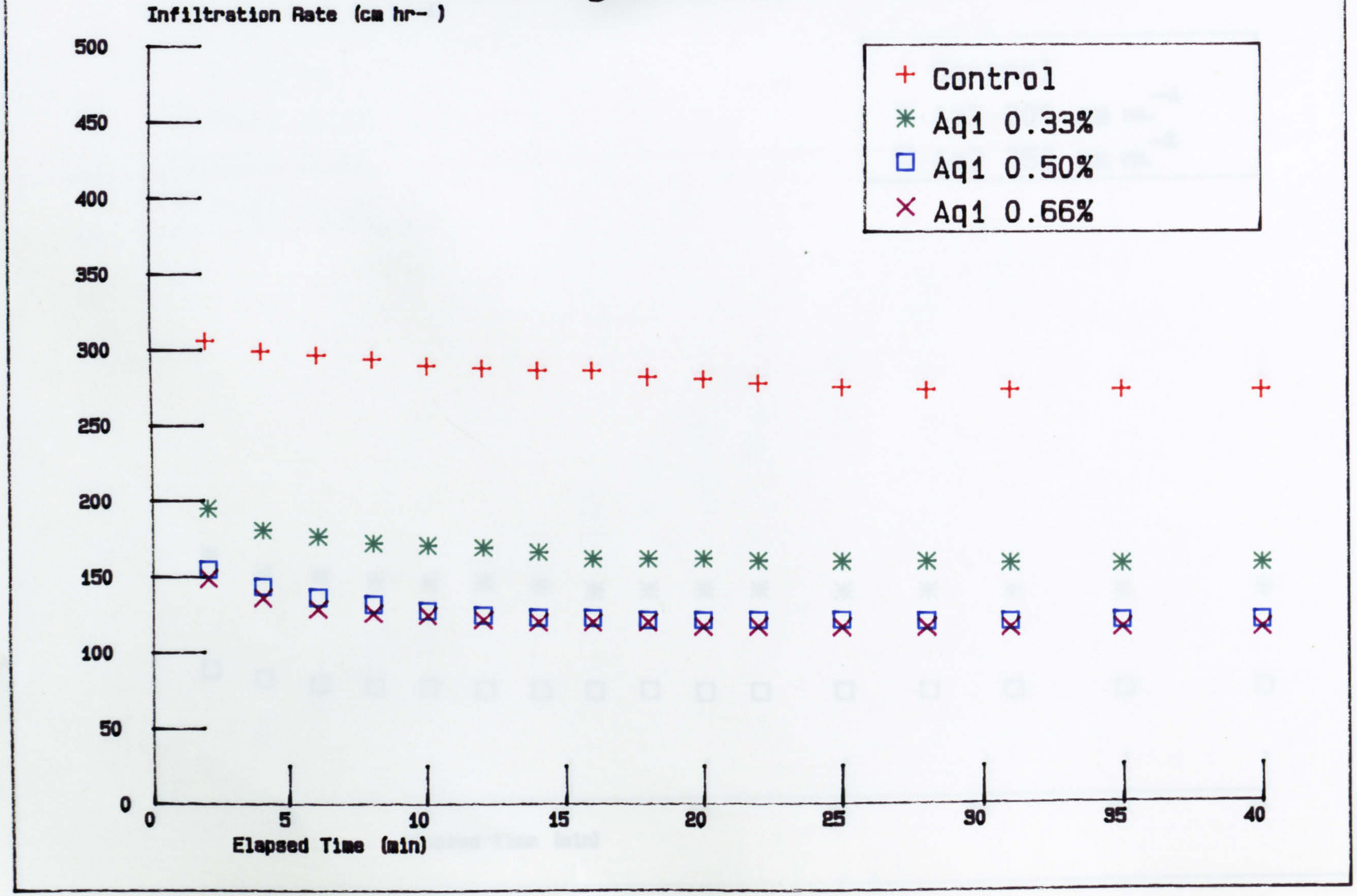


Fig. 5.11: Effect of Aq2 on Infiltration Rate in Druridge Sands.

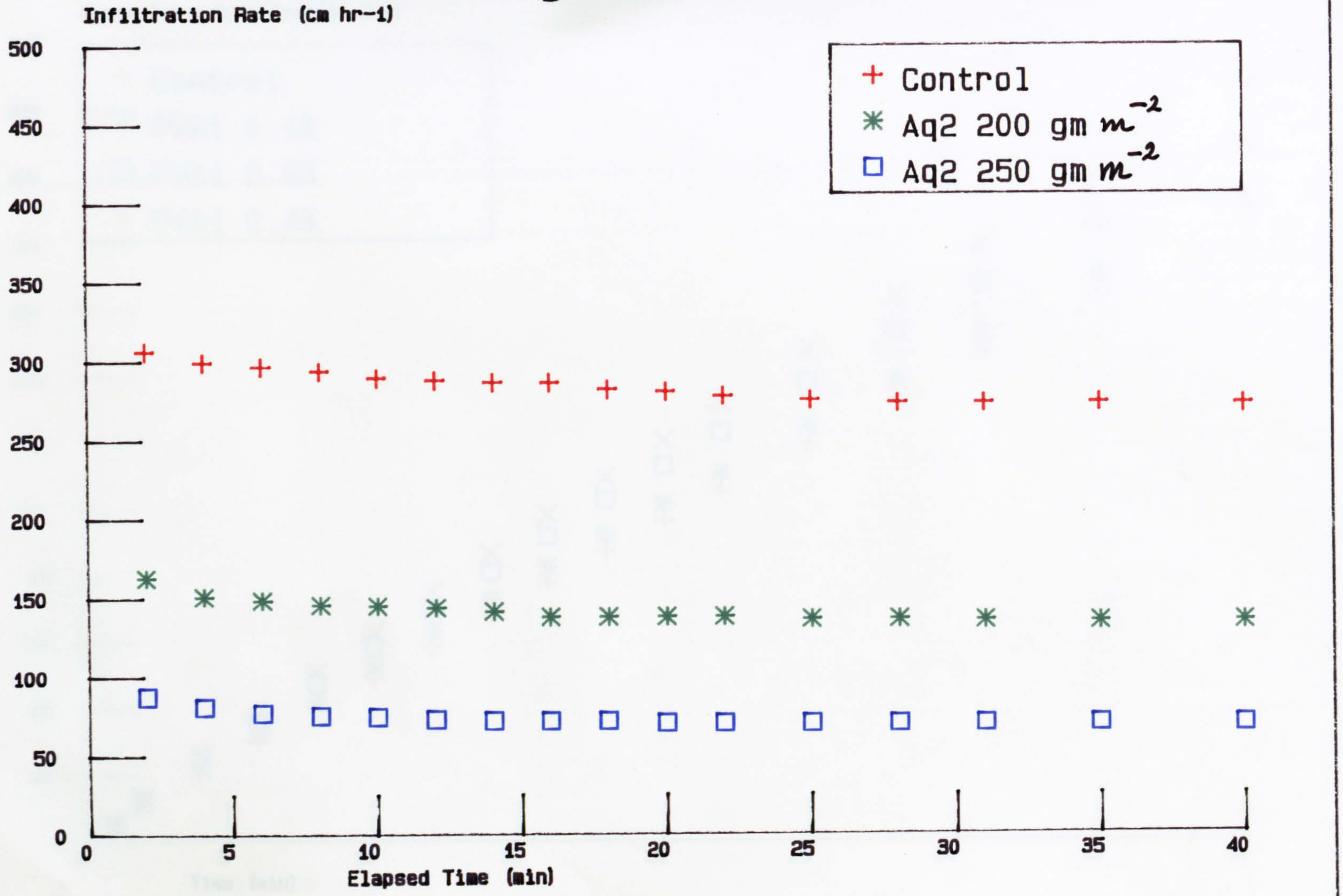


Fig. 5.12: Effect of PVA1 on Accumulated Infiltration in Druridge Sands

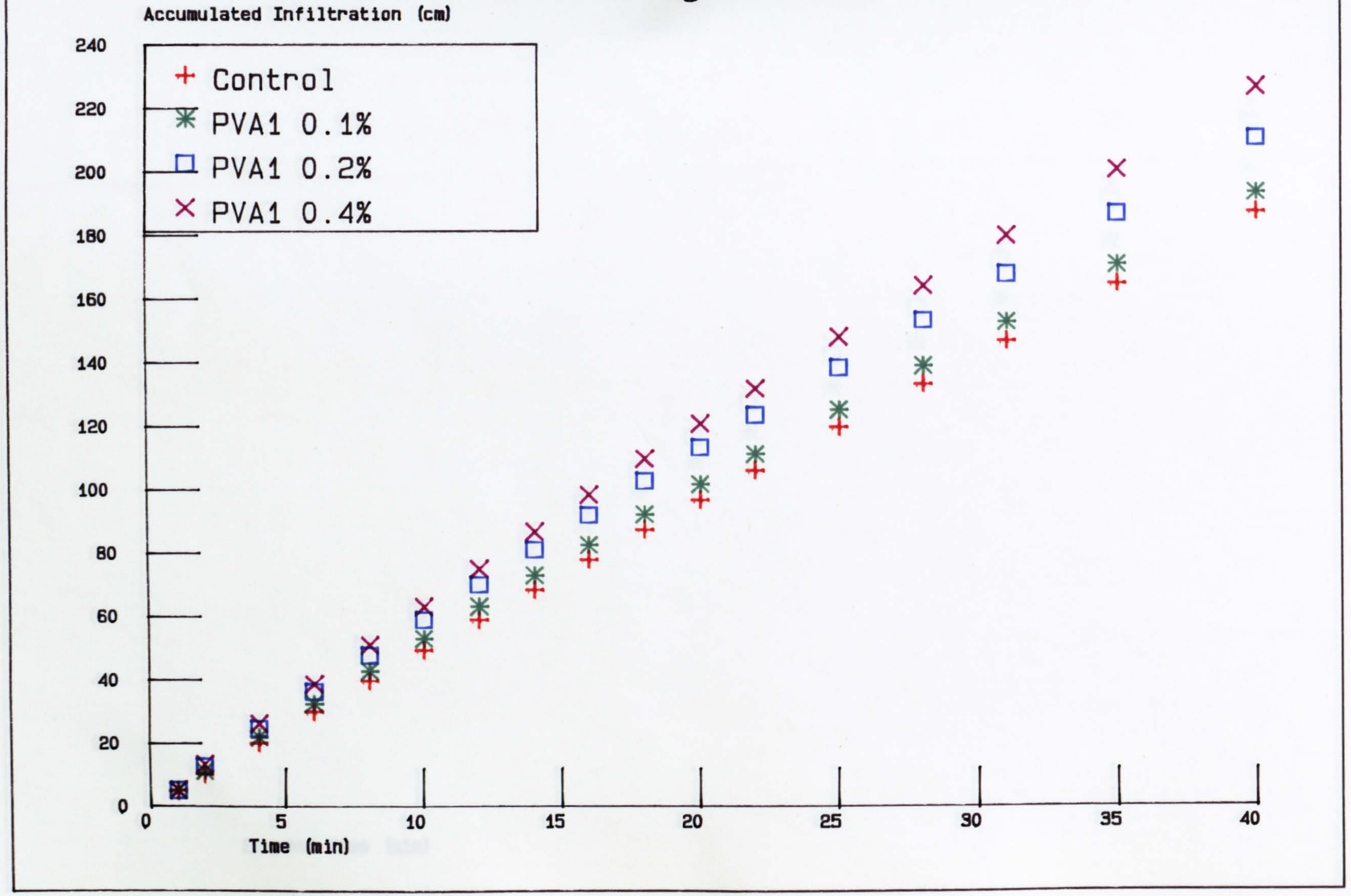


Fig. 5.13: Effect of PVA2 on Accumulated Infiltration in Druridge Sands

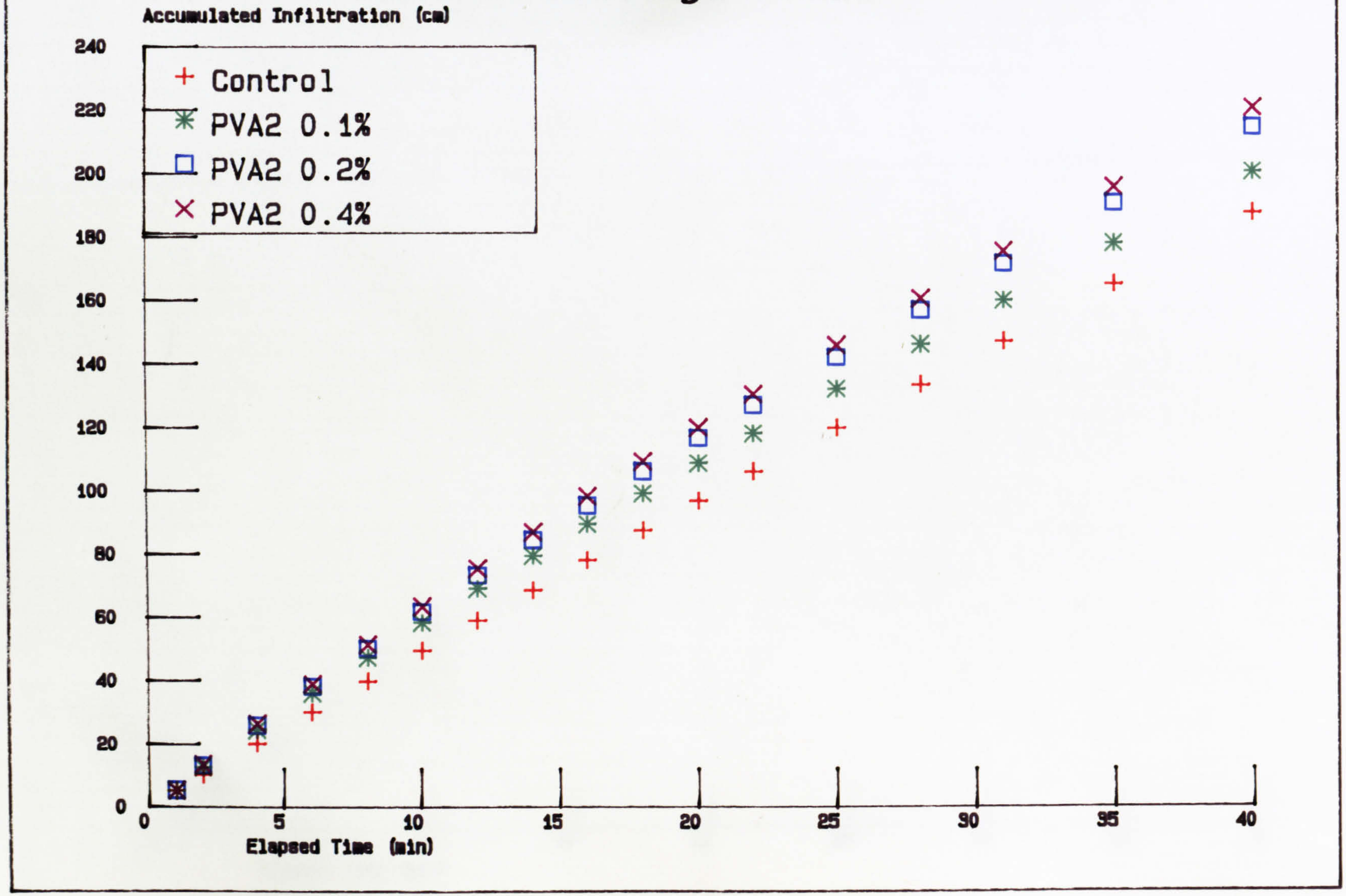


Fig. 5.14: Effect of PEG3 on Accumulated Infiltration in Druridge Sands

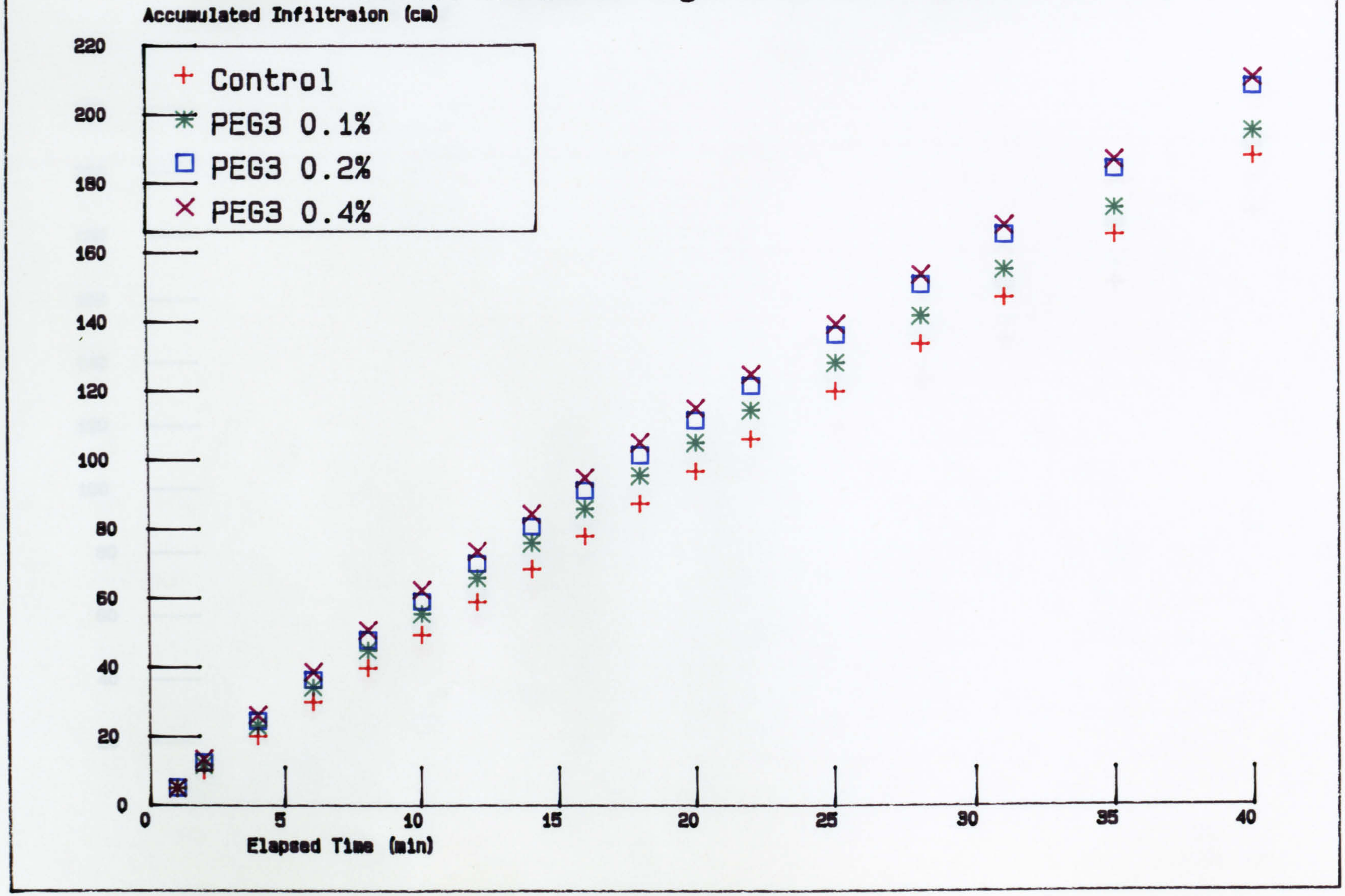


Fig. 5.15: Effect of PEG4 on Accumulated Infiltration in Druridge Sands

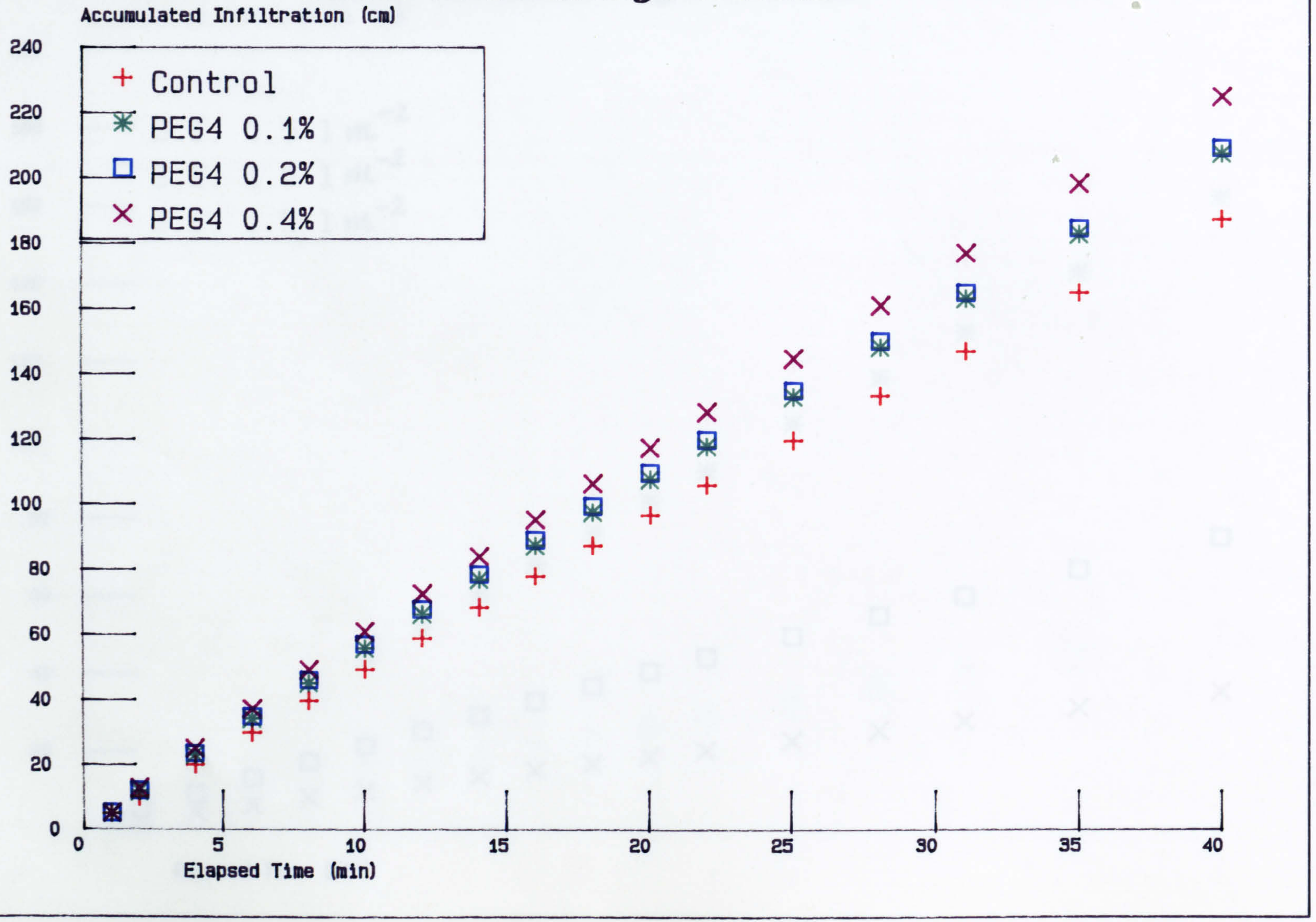


Fig. 5.16: Effect of B.E. on Accumulated Infiltration in Druridge Sands

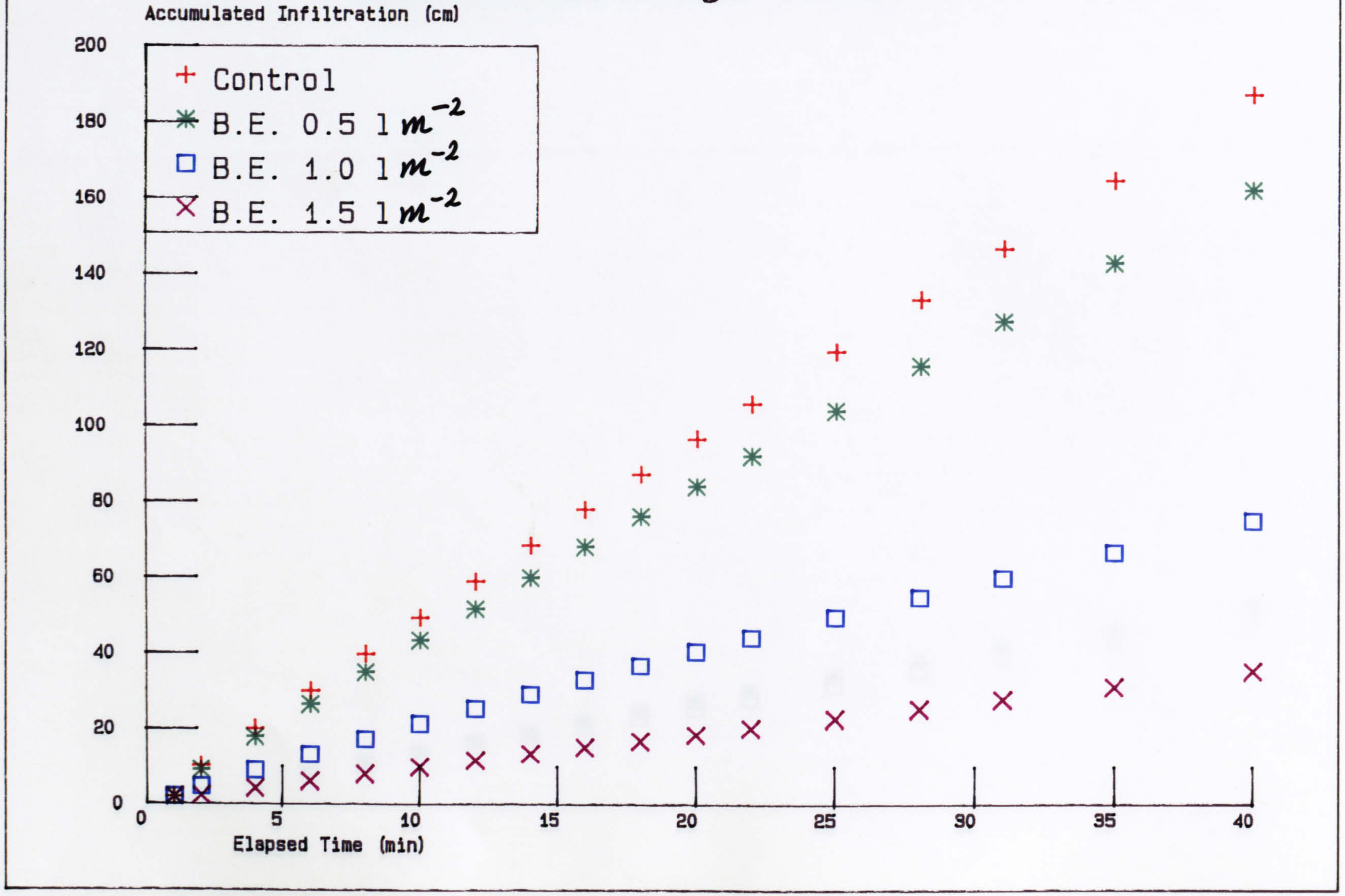


Fig. 5.17: Effect of F.E. on Accumulated Infiltration in Druridge Sands

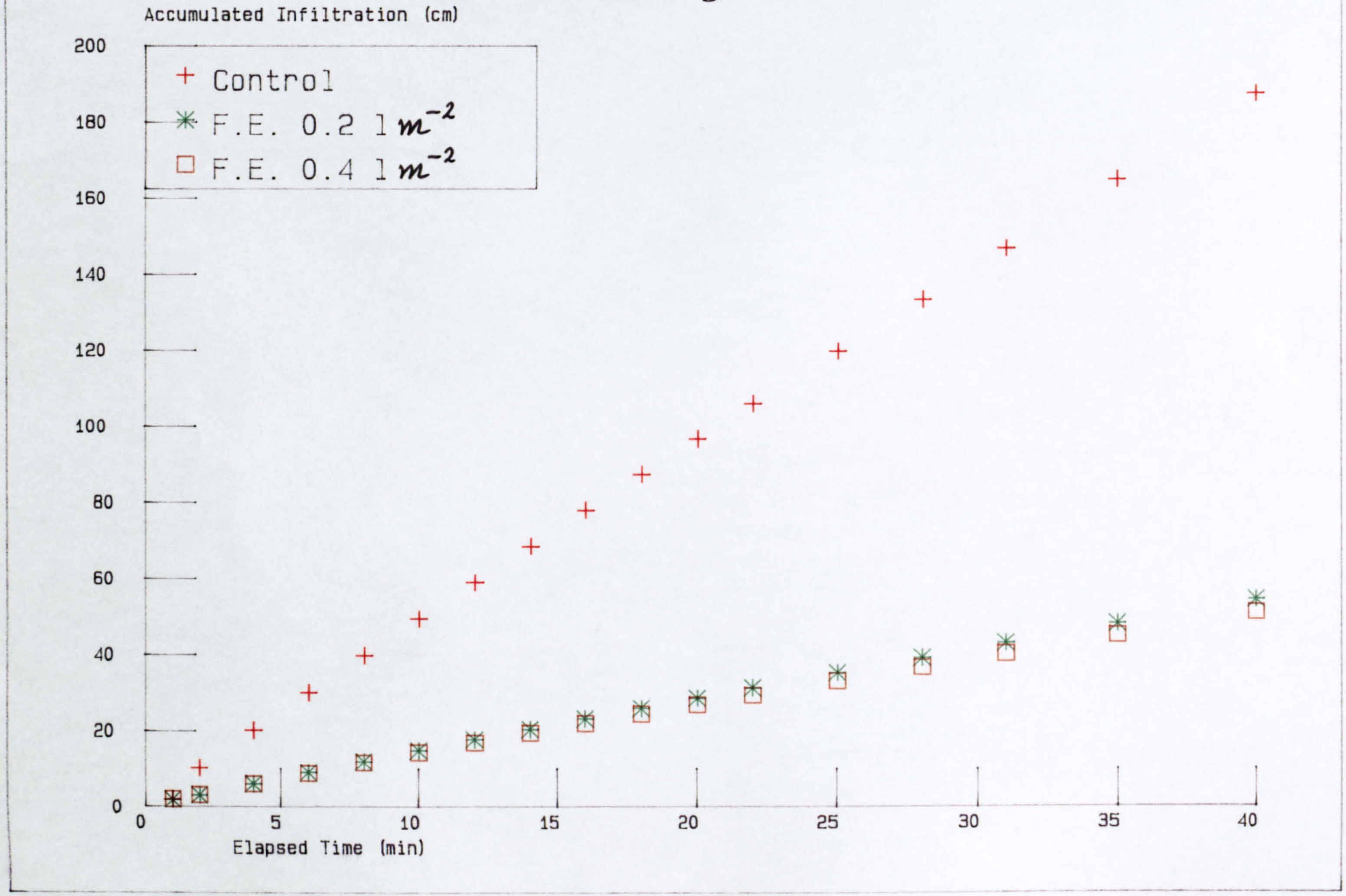


Fig. 5.18: Effect of V1 on Accumulated Infiltration in Druridge Sands

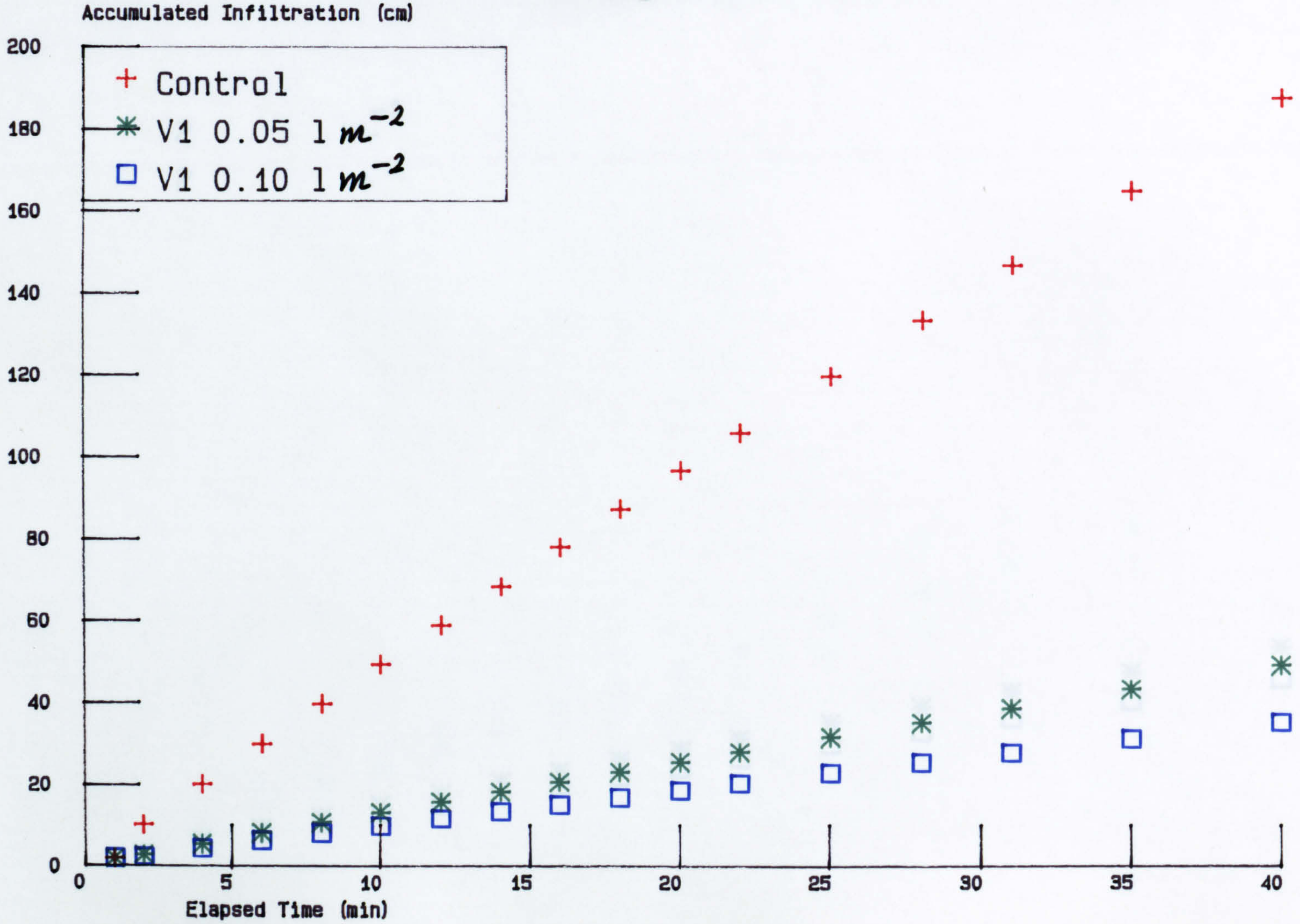


Fig. 5.19: Effect of V2 on Accumulated Infiltration in Druridge Sands

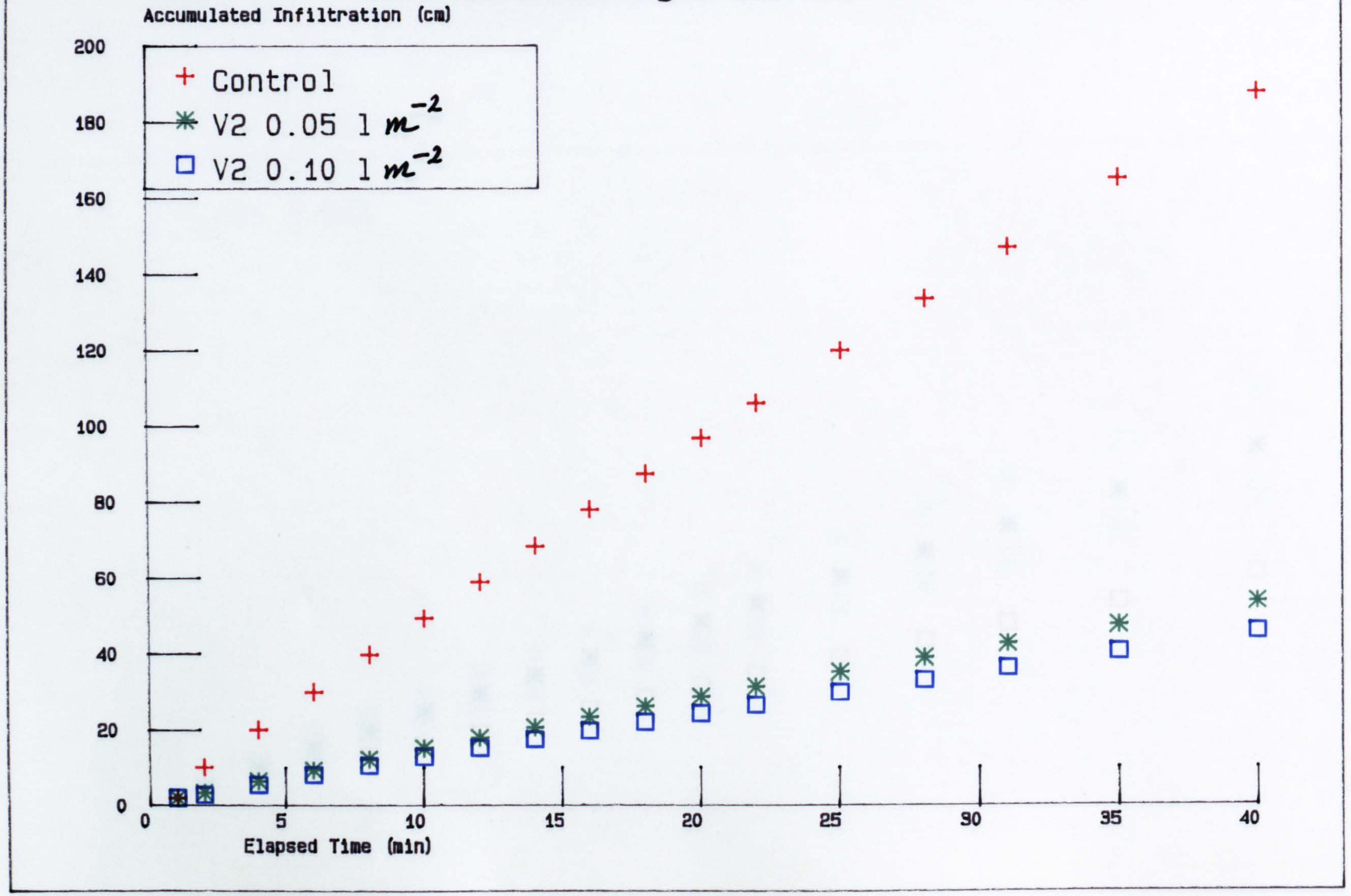


Fig. 5.20: Effect of V3 on Accumulated Infiltration in Druridge Sands

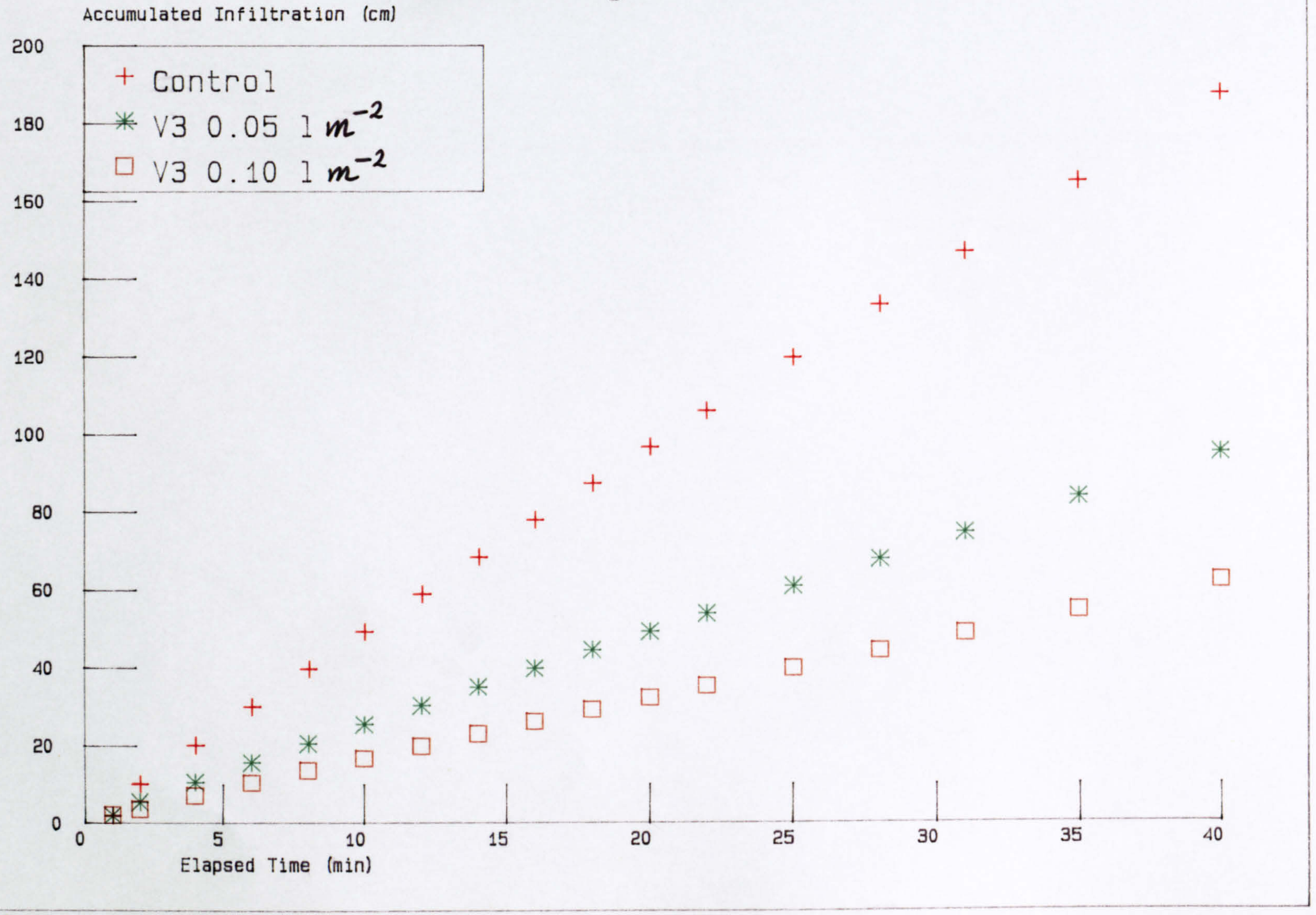


Fig. 5.21: Effect of Aq1 on Accumulated Infiltration in Druridge Sands

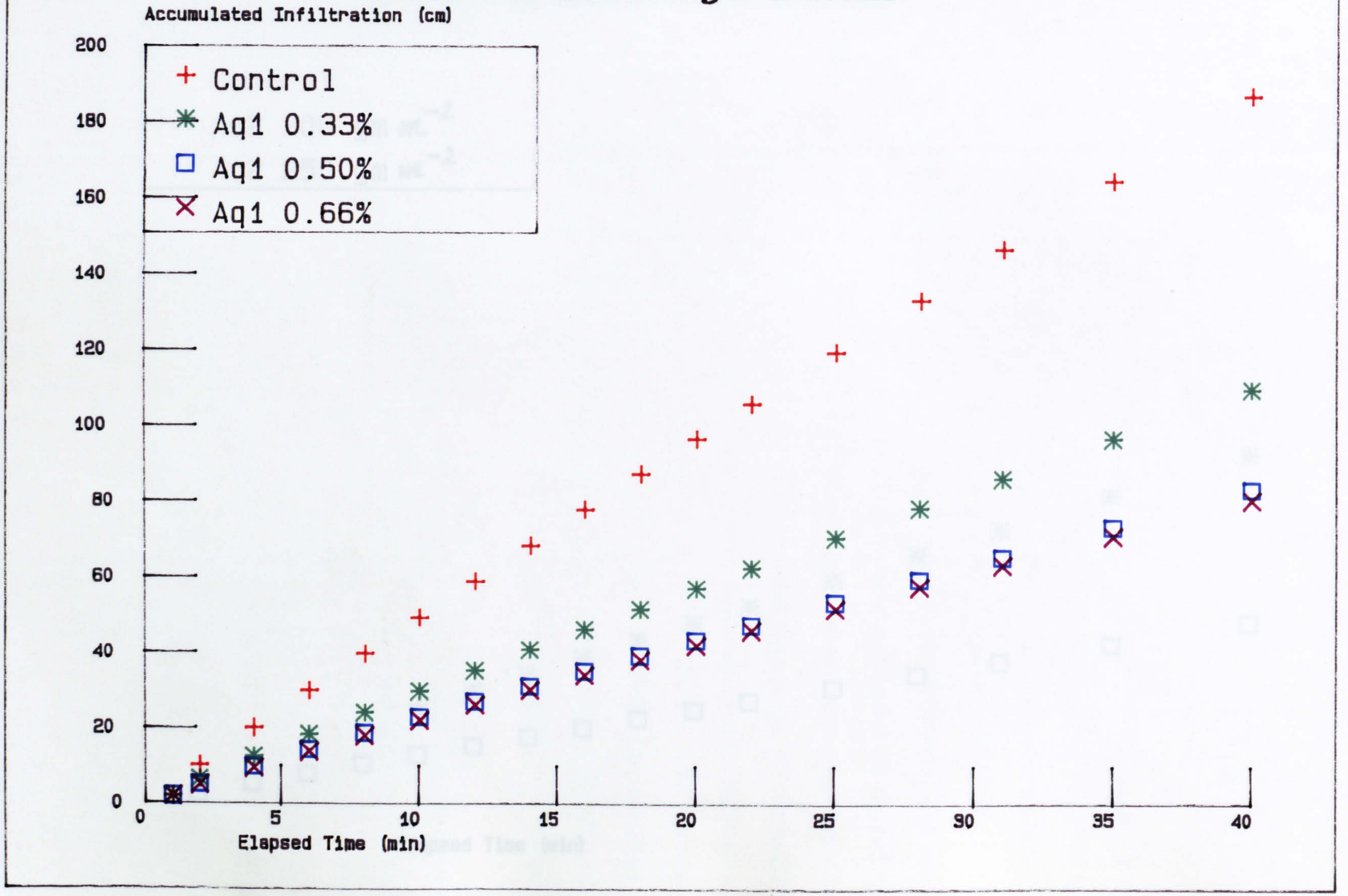
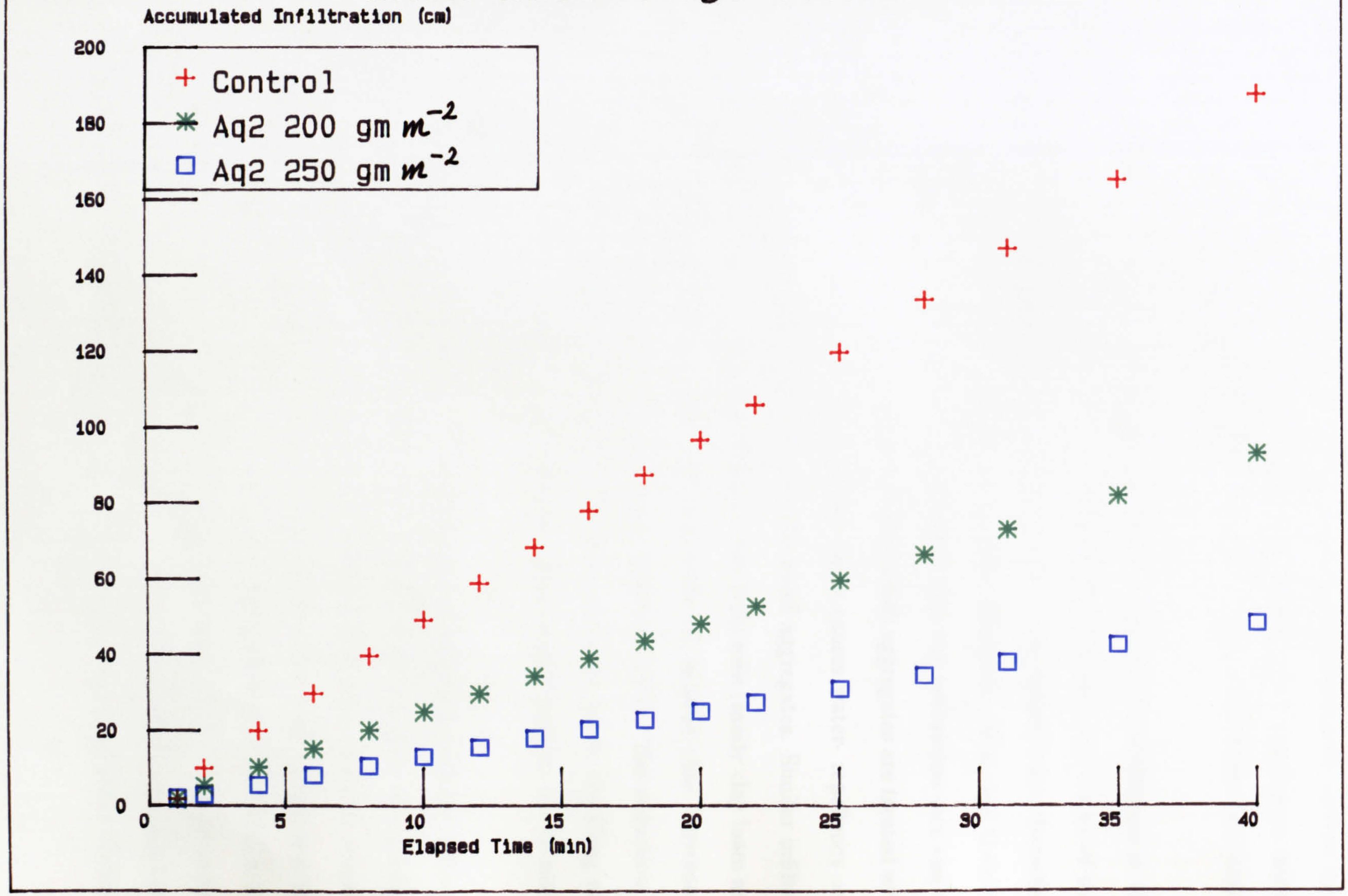


Fig. 5.22: Effect of Aq2 on Accumulated Infiltration in Druridge Sands.



acceptable infiltration rate of 0.25 cm hr^{-1} (Richards, 1969).

Increases in infiltration rates and accumulated infiltrations with PVA1; PVA2; PEG3; PEG4 treatments, could be due to the production of a stable surface layer with large number of macropores. The increase in infiltration rates are in agreement with the results obtained by (Helalia et al., 1988; and Helalia and Letey, 1988).

The reduction in the infiltration rates and accumulated infiltrations in the sand samples treated with V1; V2; V3; B.E.; F.E.; Aq1 and Aq2 chemical materials (figures 5.5 - 5.11 and 5.16 - 5.22) was due to the hydrophobic characters of the sand surfaces treated with these chemicals (Gabriels, 1974; and Gabriels and De Boodt, 1975). Gabriels (1974) indicated that the infiltration rate can be blocked by a high contact angle, especially when small aggregates are treated with a water-proofing material. The high contact angle causes water- repellency and prevents water entering the pores between the small aggregates. Similar infiltration tests carried out by Al-Debagi (1983) on two Iraqi soils (sandy clay loam and clayey) treated with bitumen emulsions and crude oil, showed close agreement with the contact angles values determined by Gabriels (1974). The reduction in the infiltration rates and accumulated infiltrations could be due to the filling and blocking of some pores between sand particles in the treated layer by the chemical materials (Taimurazova, 1967).

The infiltration rate in both control sand samples and those with the different chemical treatments reduced with the time. The rate of reduction was greatest at the start of the test, decreasing as time elapsed. The time taken to reach a steady state varied with various chemical treatments, but in all cases it was less than 25 minutes in all treatments. The initial rapid reduction in infiltration has been attributed by Michael (1978), to three possible causes: First, the antecedent soil moisture content, which has a considerable effect on the initial rate and total amount of infiltration (both decrease as the soil moisture content rises). Second,

transfer of the fine particles from the surface layer, resulting in the clogging of pores in the lower layers, and the reorientation of particles within the sand column, thus reducing water movement (Felhendler et al., 1974; Frenkel et al., 1978; and Michael, 1978). Thirdly, the expansion of 2:1 lattice clay minerals and any humus present, will rapidly reduce water movement.

Applying the data used for drawing figures (5.12 - 5.22) in the following equation introduced by Michael (1978):

$$Y = at^{\alpha} + b \qquad or \qquad log(Y - b) = loga + \alpha logt$$

the figures (23-33) were obtained. These all indicate the effect of the chemical materials on the accumulated infiltration on a log-log relationship.

While, good linear relationships are indicated in all the figures (5.23 - 5.33), there is no need to use Michael's method for the relationship between accumulated infiltration and the elapsed time, especially in dune sand samples, for the following reasons:-

1. The regression coefficients (r) between the observed accumulated infiltrations and the elapsed time derived from the control and from all chemical treatments data, are extremly high (table 5.1). These are not much different to the regression coefficients derived from the data calculated by Michael's method. All the points of both correlations, observed accumulated infiltration-elapsed time, and calculated infiltration- elapsed time are dropping on a linear relationships, as all rcal values are larger than rtab of (0.6226) at the 1% level of significance (Gheyi and VanBladel, 1975).
2. a and b values calculated from both observed and calculated accumulated infiltrations (Y) values are very close.
3. the percentage deviation between the infiltrated water depths calculated from Michael's method and the observed one (appendix tables 5.1 - 5.12b) were very small. They were always less than 1.0%.

Fig. 5.23: Effect of PVA1 on Accumulated Infiltration in Druridge Sands (log-log relationship)

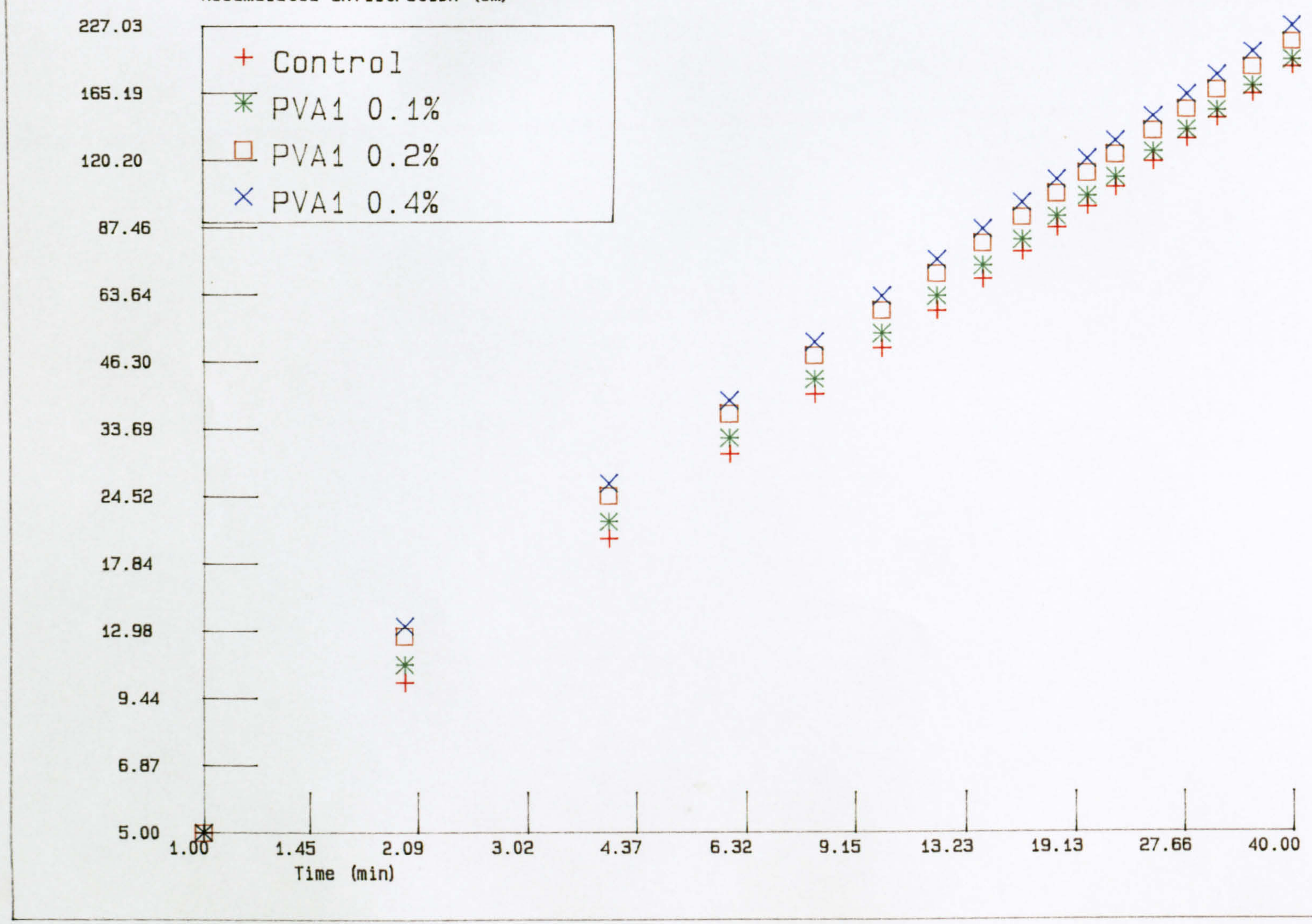


Fig. 5.24: Effect of PVA2 on Accumulated Infiltration in Druridge Sands (log–log relationship)

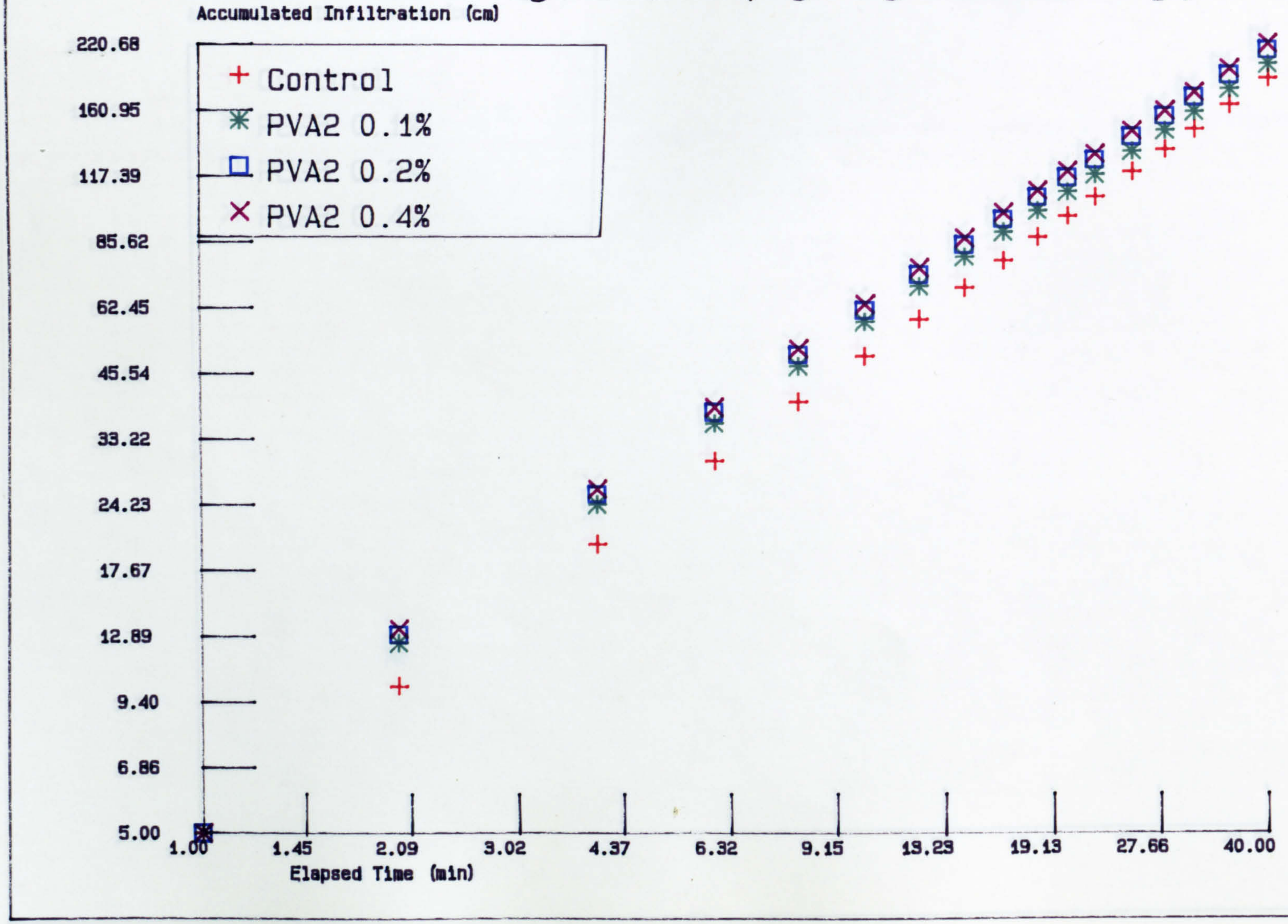


Fig. 5.25: Effect of PEG3 on Accumulated Infiltration in Druridge Sands (log–log relationship)

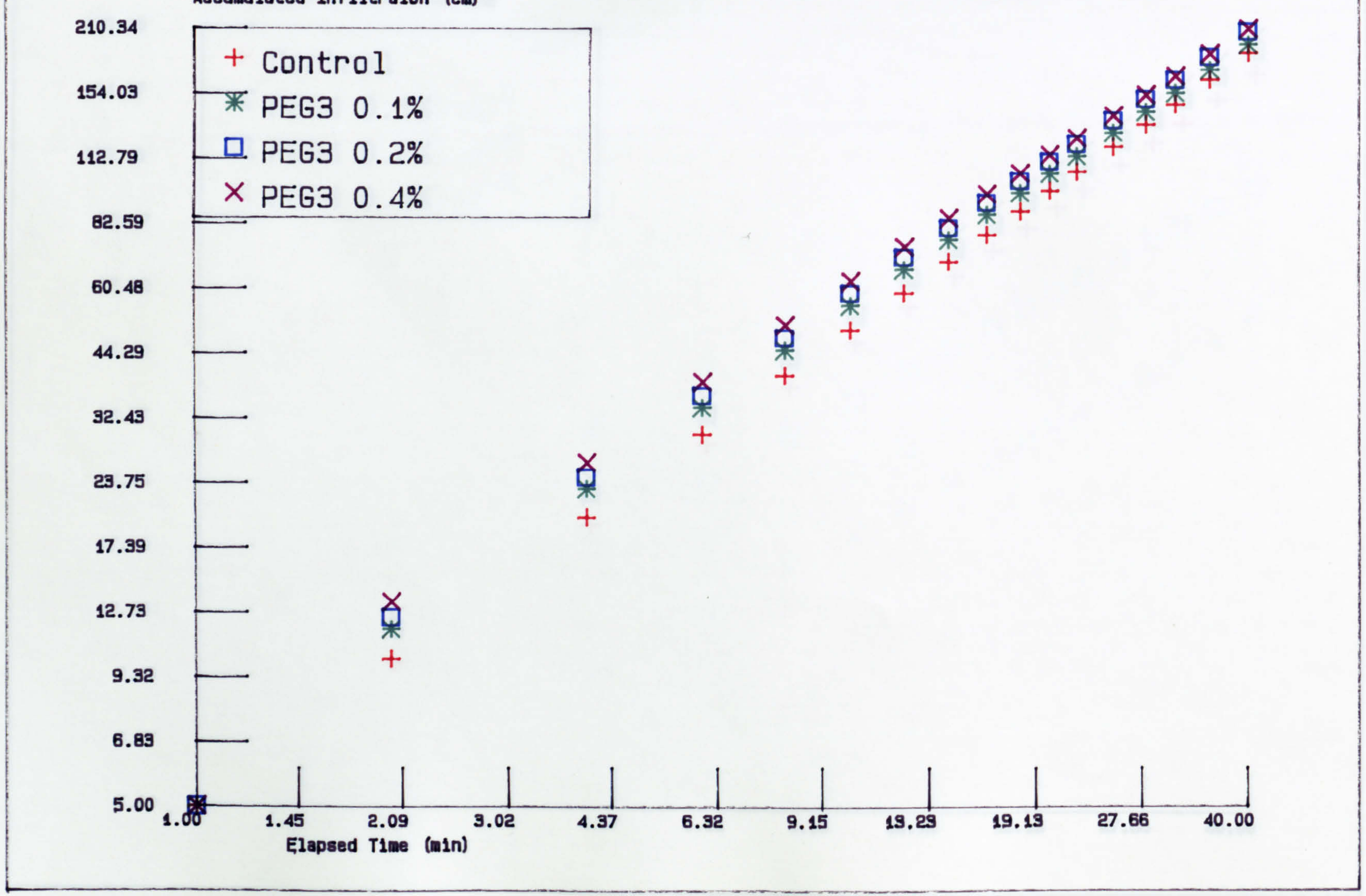


Fig. 5.26: Effect of PEG4 on Accumulated Infiltration in Druridge Sands (log–log relationship)

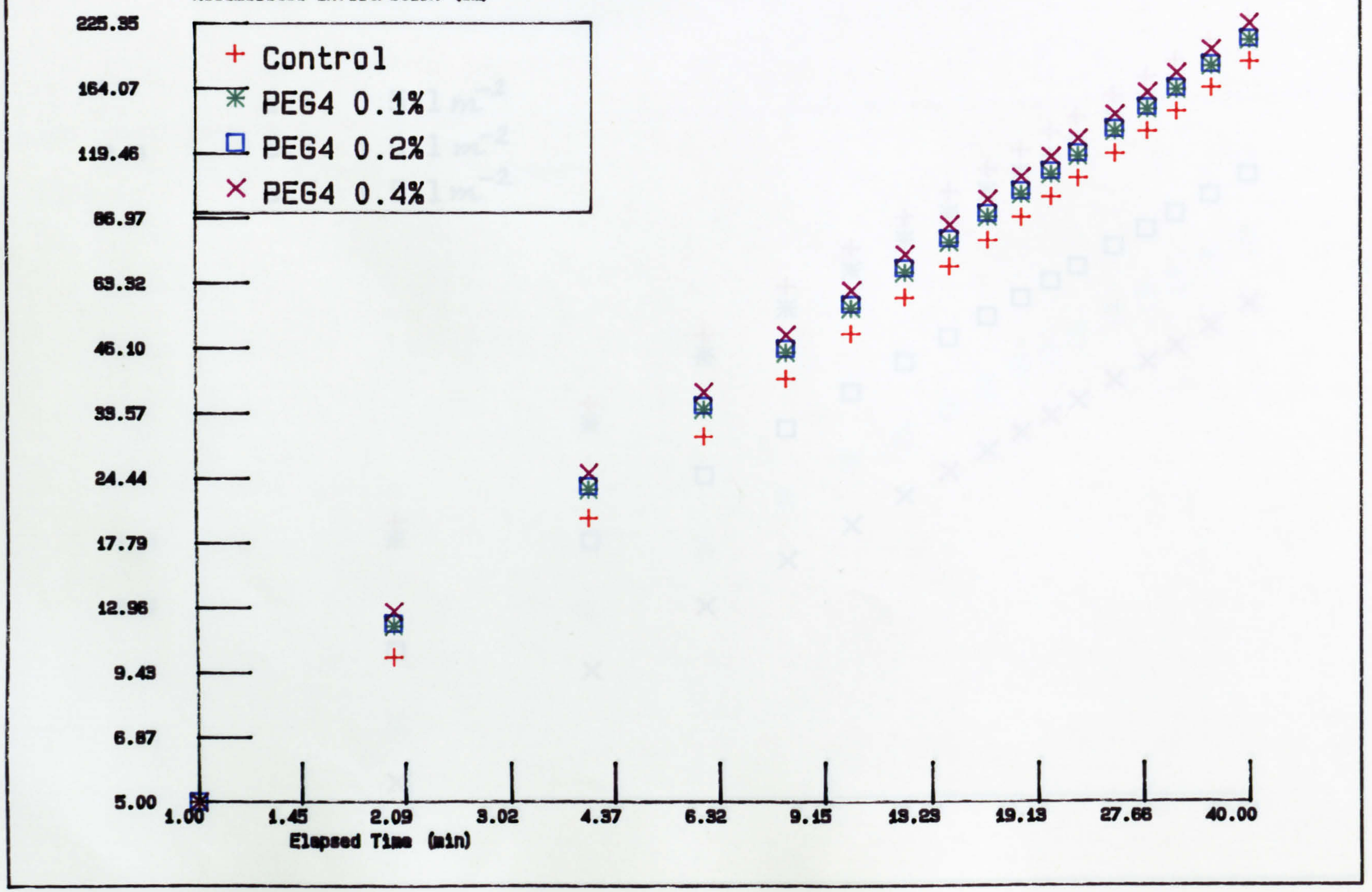


Fig. 5.27: Effect of B.E. on Accumulated Infiltration in Druridge Sands (log–log relationship)

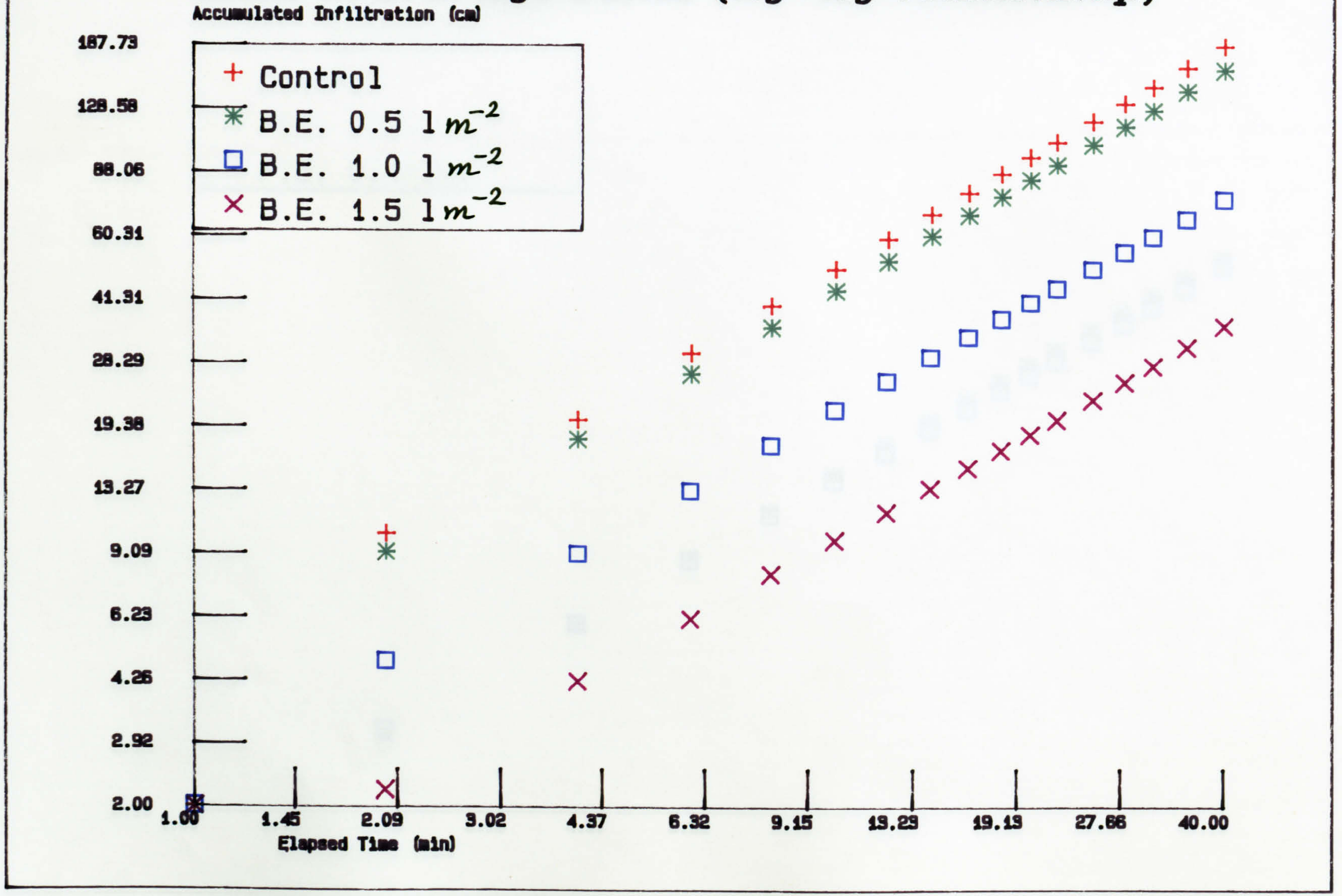


Fig. 5.28: Effect of F.E. on Accumulated Infiltration in Druridge Sands (log–log relationship)

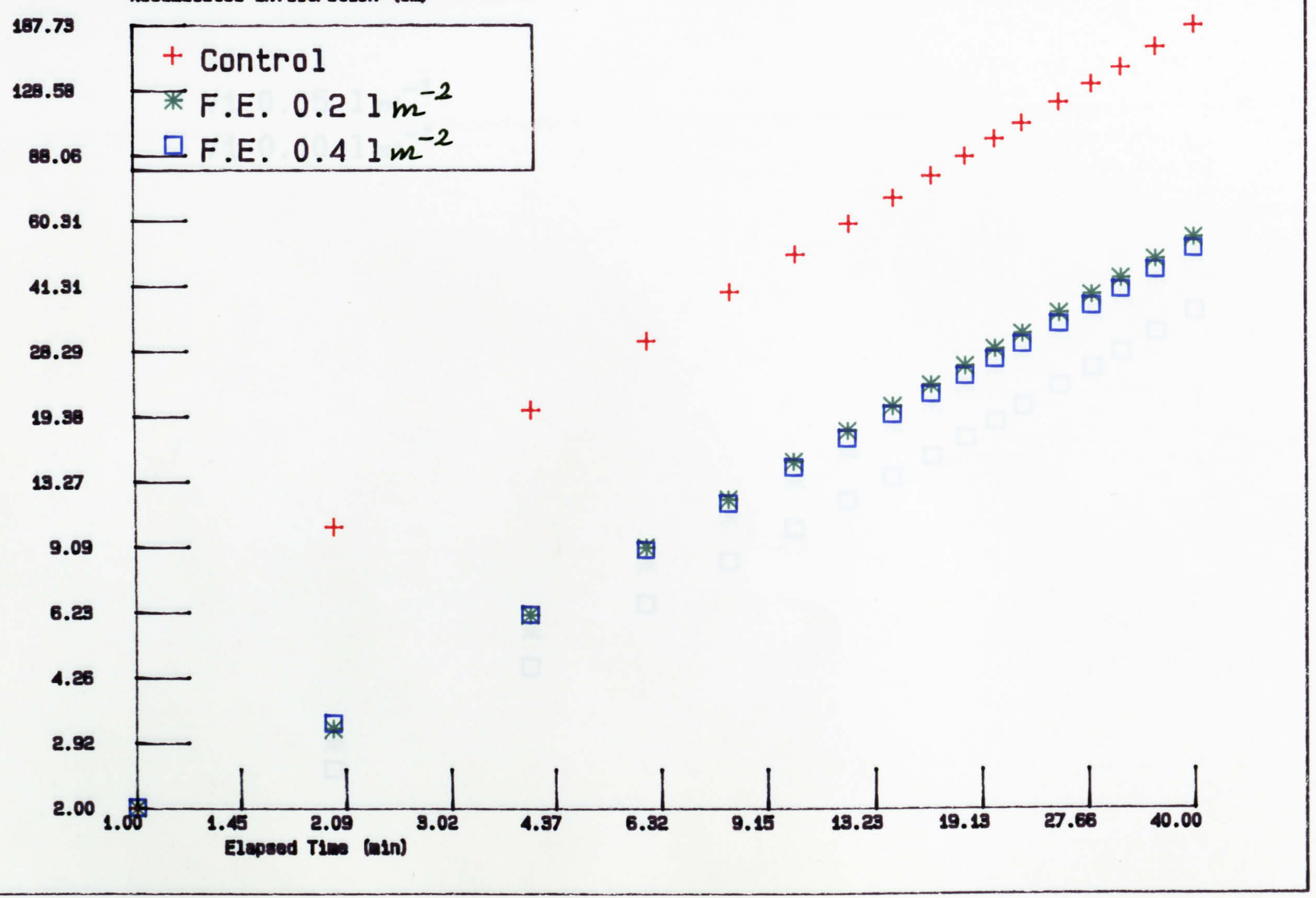


Fig. 5.29: Effect of V1 on accumulated Infiltration in Druridge Sands (log–log relationship)

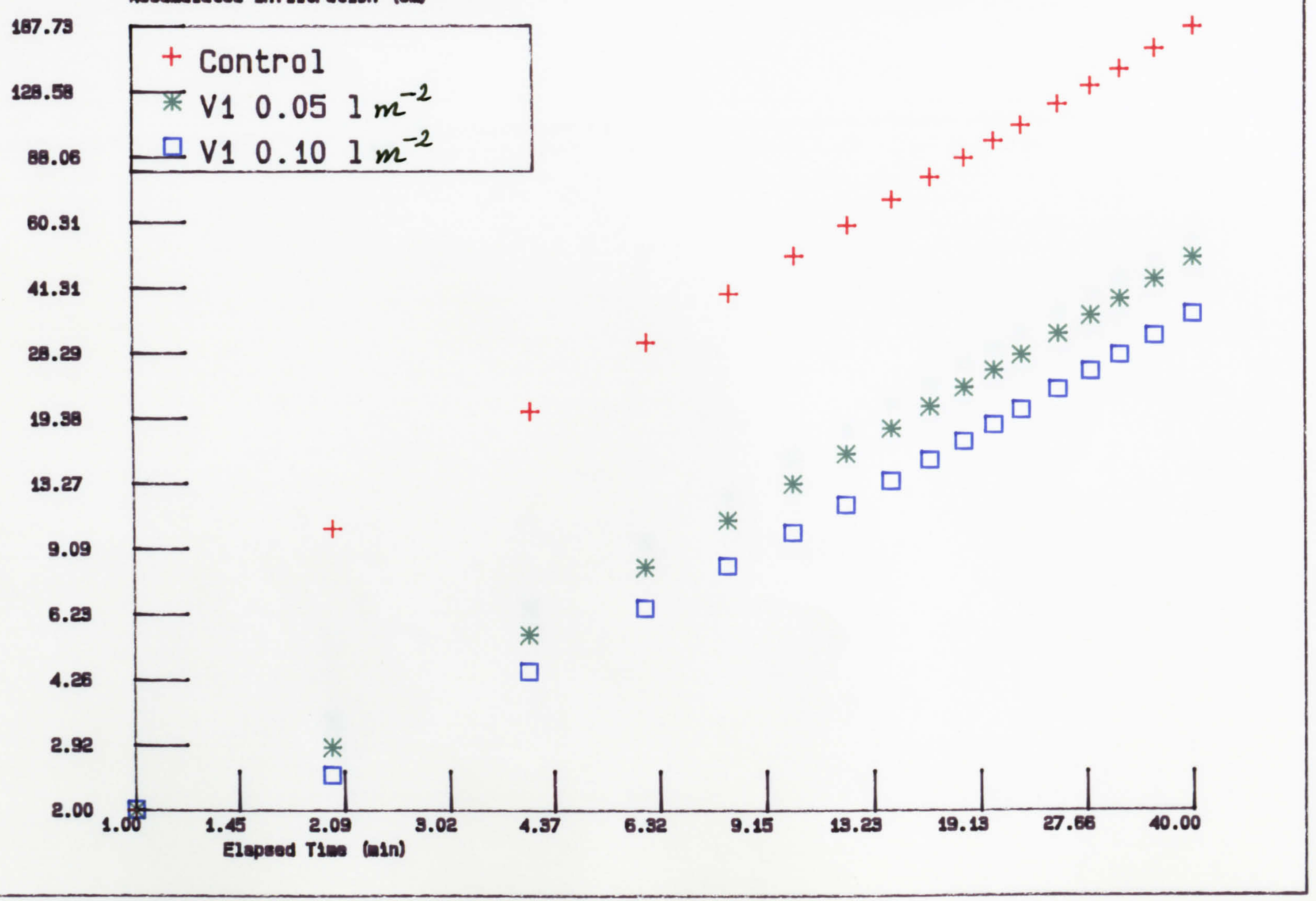


Fig. 5.30: Effect of V2 on Accumulated Infiltration in Druridge Sands (log–log relationship)

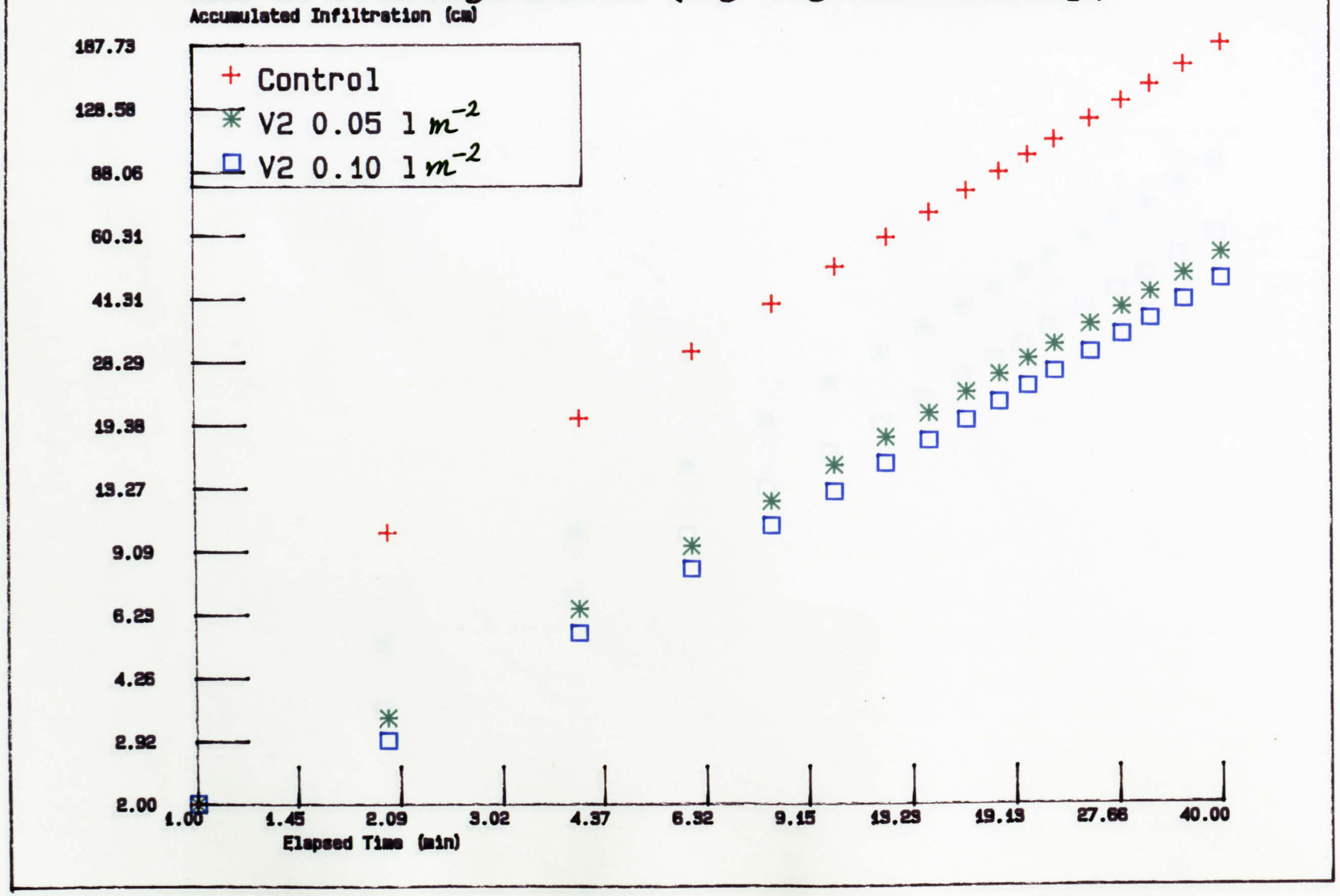


Fig. 5.31: Effect of V3 on Accumulated Infiltration in Druridge Sands (log–log relationship)

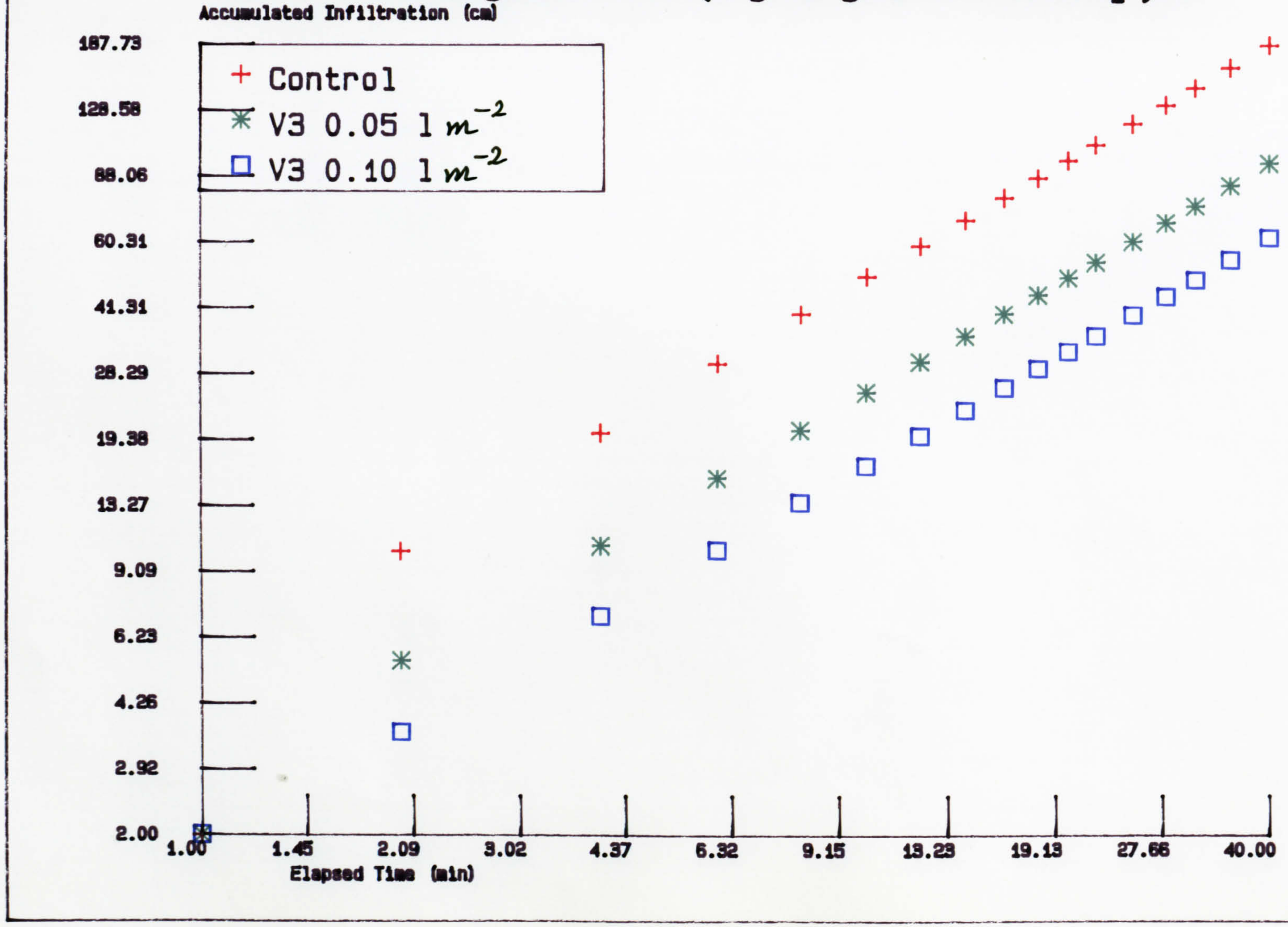


Fig. 5.32: Effect of Aq1 on Accumulated Infiltration in Druridge Sands (log–log relationship)

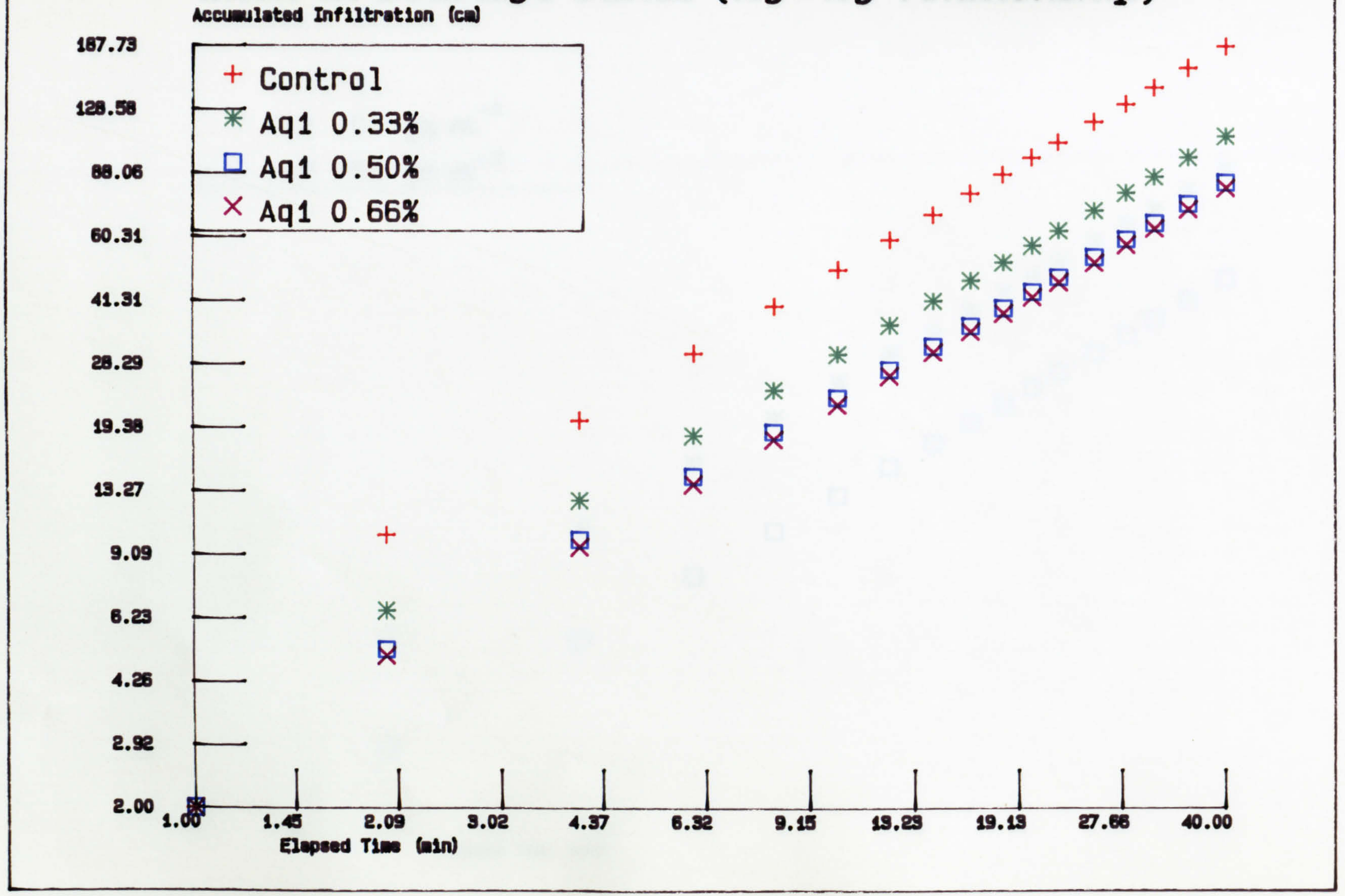


Fig. 5.33: Effect of Aq2 on Accumulated Infiltration in Druridge Sands (log–log relationship)

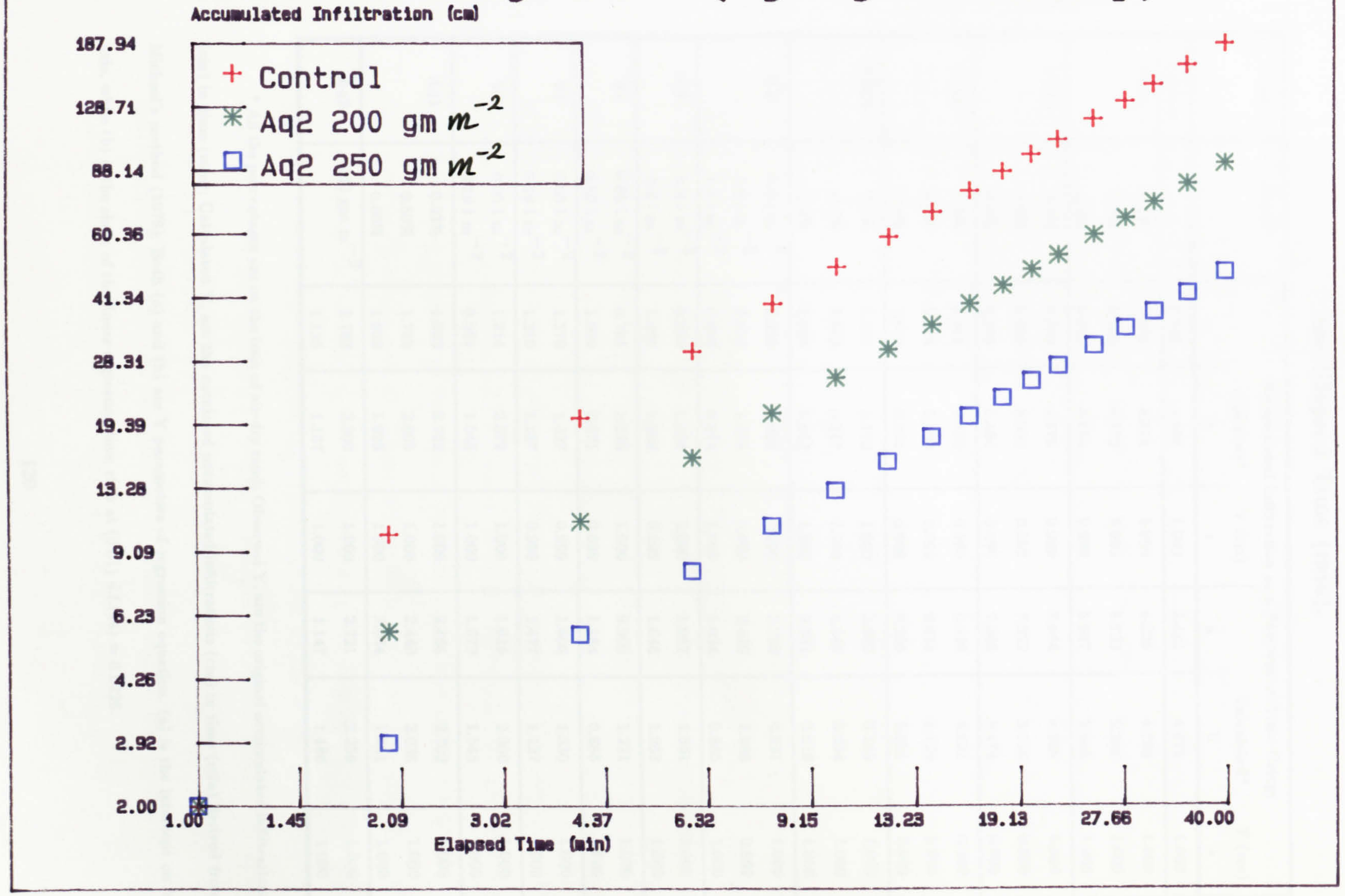


Table 5.1: Regression Coefficients and a and b Constant Values for the Relationship Between Accumulated Infiltration (cm) and the Elapsed Time (min).

Treats	Conc.*	Accumulated Infiltration as a Function of Time Using:					
		Observed*		Y (cm)	Calculated*		Y (cm)
		a	b	r	a	b	r
Control	—	2.018	4.686	1.000	2.412	4.672	1.000
PVA1	0.1%	3.573	4.824	1.000	4.226	4.796	1.000
	0.2%	5.140	5.272	0.999	5.723	5.260	1.000
	0.4%	5.002	5.664	0.999	5.867	5.638	1.000
PVA2	0.1%	6.363	4.978	0.999	7.664	4.928	0.999
	0.2%	6.250	5.353	0.999	7.252	5.316	0.999
	0.4%	6.479	5.494	0.999	7.386	5.474	0.999
PEG3	0.1%	5.361	4.852	0.999	6.229	4.821	0.999
	0.2%	5.474	5.168	0.999	6.634	5.129	0.999
	0.4%	7.633	5.204	0.998	8.296	5.211	0.999
PEG4	0.1%	3.130	5.172	1.000	3.882	5.145	1.000
	0.2%	3.663	5.217	1.000	4.149	5.204	1.000
	0.4%	3.624	5.612	1.000	3.931	5.616	1.000
B.E.	0.5 l m^{-2}	2.226	4.054	1.000	2.798	4.031	1.000
	1.0 l m^{-2}	2.059	1.875	0.999	2.426	1.868	0.999
	1.5 l m^{-2}	0.823	0.874	1.000	1.034	0.865	1.000
F.E.	0.2 l m^{-2}	0.958	1.364	1.000	1.067	1.361	1.000
	0.4 l m^{-2}	1.275	1.268	0.999	1.646	1.253	1.000
V1	0.05 l m^{-2}	0.781	1.225	1.000	0.900	1.221	1.000
	0.10 l m^{-2}	1.000	0.871	0.999	1.184	0.865	1.000
V2	0.05 l m^{-2}	1.379	1.337	0.999	1.606	1.330	1.000
	0.10 l m^{-2}	1.210	1.137	0.999	1.477	1.127	1.000
V3	0.05 l m^{-2}	1.314	2.372	1.000	1.616	2.360	1.000
	0.10 l m^{-2}	0.961	1.546	1.000	1.079	1.545	1.000
Aq1	0.33%	1.893	2.732	1.000	2.466	2.702	1.000
	0.50%	1.785	2.065	1.000	2.440	2.036	1.000
	0.66%	1.609	1.998	1.000	2.034	1.981	1.000
Aq2	200 gm m^{-2}	1.783	2.300	1.000	2.721	2.259	1.000
		1.125	1.187	1.000	1.147	1.186	1.000

* All the percentages are on the base of air-dry sand; Observed Y, are the original accumulated infiltrations (cm) in time (min); Calculated Y, are the caculated accumulated infiltrations (cm) in time (min) derived from Michael's method (1978); Both (a) and (b) are Y parameters of regression equation, (a) is the intercept on Y axis, while (b) is the slope of the linear regression line; rtab at (0.01) d.f.(14) = 0.6226.

b. Effect of Soil Stabilizers on the Hydraulic Conductivity and Intrinsic Permeability* of the Sand:

The saturated hydraulic conductivity is an important soil physical characteristic for determining the maximum capacity of soils to conduct water (Lauren et al., 1988). Tables (5.2 - 5.12) show the saturated hydraulic conductivities (cm hr^{-1}) of sand under the various treatments, while tables (5.13 - 5.23) indicate its intrinsic permeabilities (cm^2). These show a similar pattern to the infiltration rates, whereby saturated hydraulic conductivities and intrinsic permeabilities of all samples decreased with time. This again can be attributed to the reorientation of sand particles during infiltration, and the clogging of pores within the sand columns by finer particles (Michael, 1978; and Helalia et al., 1988). Photo (5.2) shows two layers of sand in each infiltration column caused by the eluviation and reorientation of the finer sand particles.

As previously, PVA1; PVA2; PEG3; and PEG4 increased both the saturated hydraulic conductivity and the intrinsic permeability of the sands when compared with the control, whilst B.E.; F.E.; V1; V2; V3; Aq1 and Aq2 treatments reduced both. The effect of changes in concentration is the same as for infiltration i.e. as

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* *The permeability of soil, in a qualitative sense, refers to the readiness with which the soil conducts or transmits fluids. In a quantitative sense, when permeability is expressed with numbers, it seems desirable that permeability be defined as a property of the porous medium alone and independent of the fluid used in its measurement. These distinctions represent increased specialization in the use of these terms as approved by the Soil Science Society of America (1952). No change in the qualitative use of the word "permeability" is involved. In the quantitative sense, involving numerical values, the term "intrinsic permeability" will mostly be used and will refer to a length-squared measurement that may be identified in a general way to the cross-sectional area of some equivalent or effective size of pore (Richards, 1969).*

Table 5.2: Effect of PVA1 on Saturated Hydraulic Conductivity of Druridge Bay Sand.

Time	Saturated Hydraulic Conductivity (cm hr^{-1}) PVA1 Concentrations*			
(min)	0.0%	0.1%	0.2%	0.4%
2.00	252.48	258.84	285.24	305.28
4.00	248.34	253.50	283.74	299.16
6.00	241.74	246.66	277.14	295.98
8.00	240.06	239.82	271.80	293.04
10.00	237.36	238.08	266.16	285.72
12.00	236.64	238.08	262.98	281.58
15.00	235.38	235.26	258.06	275.94
18.00	232.50	233.28	257.22	273.48
21.00	230.88	231.36	253.14	272.22
25.00	227.22	229.20	248.46	267.78
30.00	224.58	226.74	244.20	267.66

Table 5.3: Effect of PVA2 on Saturated Hydraulic Conductivity of Druridge Bay Sand.

Time	Saturated Hydraulic Conductivity (cm hr^{-1}) PVA2 Concentrations*			
(min)	0.0%	0.1%	0.2%	0.4%
2.00	252.48	274.74	300.36	297.42
4.00	248.34	263.76	293.04	290.58
6.00	241.74	258.12	285.72	282.06
8.00	240.06	251.52	282.06	280.08
10.00	237.36	248.58	271.80	274.26
12.00	236.64	243.00	266.88	268.86
15.00	235.38	240.12	261.12	265.86
18.00	232.50	239.82	259.02	265.50
21.00	230.88	237.06	257.22	264.06
25.00	227.22	233.58	252.60	263.10
30.00	224.58	229.86	250.26	260.70

* All (%) are on the base of air-dry sand.

Table 5.4: Effect of PEG3 on Saturated Hydraulic Conductivity of Druridge Bay Sand.

Time	Saturated Hydraulic Conductivity (cm hr^{-1}) PEG3 Concentrations*			
(min)	0.0%	0.1%	0.2%	0.4%
2.00	252.48	261.78	277.14	275.94
4.00	248.34	255.90	268.14	272.76
6.00	241.74	250.32	262.98	265.44
8.00	240.06	244.92	258.36	256.38
10.00	237.36	238.56	254.70	254.70
12.00	236.64	236.88	251.76	252.00
15.00	235.38	232.80	249.06	249.90
18.00	232.50	232.32	246.78	249.60
21.00	230.88	229.86	244.68	246.66
25.00	227.22	225.90	241.02	244.80
30.00	224.58	222.30	239.40	242.22

Table 5.5: Effect of PEG4 on Saturated Hydraulic Conductivity of Druridge Bay Sand.

Time	Saturated Hydraulic Conductivity (cm hr^{-1}) PEG4 Concentrations*			
(min)	0.0%	0.1%	0.2%	0.4%
2.00	252.48	273.00	277.68	298.38
4.00	248.34	270.60	273.78	290.10
6.00	241.74	267.42	269.10	288.18
8.00	240.06	264.72	265.20	285.48
10.00	237.36	262.02	260.58	284.52
12.00	236.64	259.08	258.12	282.78
15.00	235.38	258.36	256.38	280.20
18.00	232.50	257.70	254.28	277.56
21.00	230.88	255.42	253.98	274.32
25.00	227.22	254.58	252.84	270.48
30.00	224.58	250.26	251.64	266.76

* All (%) are on the base of air-dry sand.

Table 5.6: Effect of B.E. on Saturated Hydraulic Conductivity of Druridge Bay Sand.

Time (min)	Saturated Hydraulic Conductivity (cm hr^{-1}) B.E. Concentrations			
	0.0 l m^{-2}	0.5 l m^{-2}	1.0 l m^{-2}	1.5 l m^{-2}
2.00	252.48	214.44	103.32	50.04
4.00	248.34	210.00	100.86	50.04
6.00	241.74	208.56	100.62	49.56
8.00	240.06	205.14	99.42	49.56
10.00	237.36	203.40	95.46	49.32
12.00	236.64	201.24	93.54	49.32
15.00	235.38	200.40	91.80	47.88
18.00	232.50	198.60	90.84	47.70
21.00	230.88	197.82	89.70	47.04
25.00	227.22	196.08	87.90	46.26
30.00	224.58	195.36	86.64	45.72

Table 5.7: Effect of F.E. on Saturated Hydraulic Conductivity of Druridge Bay Sand.

Time (min)	Saturated Hydraulic Conductivity (cm hr^{-1}) F.E. Concentrations		
	0.0 l m^{-2}	0.2 l m^{-2}	0.4 l m^{-2}
2.00	252.48	72.78	68.40
4.00	248.34	72.30	66.66
6.00	241.74	70.80	66.66
8.00	240.06	70.56	65.22
10.00	237.36	70.32	65.22
12.00	236.64	69.84	63.96
15.00	235.38	69.66	63.66
18.00	232.50	69.18	63.66
21.00	230.88	68.52	63.18
25.00	227.22	67.74	62.88
30.00	224.58	66.60	62.22

Table 5.8: Effect of V1 on Saturated Hydraulic Conductivity of Druridge Bay Sand.

Time	Saturated Hydraulic Conductivity (cm hr^{-1})		
	V1 Concentrations		
(min)	0.0 l m^{-2}	0.05 l m^{-2}	0.10 l m^{-2}
2.00	252.48	68.40	44.70
4.00	248.34	66.42	44.22
6.00	241.74	64.20	44.22
8.00	240.06	64.20	44.22
10.00	237.36	62.52	43.98
12.00	236.64	62.52	43.74
15.00	235.38	61.56	43.44
18.00	232.50	61.38	43.14
21.00	230.88	60.54	42.30
25.00	227.22	60.06	42.12
30.00	224.58	59.46	41.88

Table 5.9: Effect of V2 on Saturated Hydraulic Conductivity of Druridge Bay Sand.

Time	Saturated Hydraulic Conductivity (cm hr^{-1})		
	V2 Concentrations		
(min)	0.0 l m^{-2}	0.05 l m^{-2}	0.10 l m^{-2}
2.00	252.48	74.70	59.10
4.00	248.34	73.02	58.62
6.00	241.74	71.82	57.90
8.00	240.06	71.28	55.44
10.00	237.36	70.08	55.20
12.00	236.64	69.84	54.96
15.00	235.38	69.18	54.24
18.00	232.50	68.88	54.06
21.00	230.88	67.74	53.88
25.00	227.22	66.66	53.70
30.00	224.58	66.06	53.34

Table 5.10: Effect of V3 on Saturated Hydraulic Conductivity of Druridge Bay Sand.

Time	Saturated Hydraulic Conductivity (cm hr^{-1})		
	V3 Concentrations		
(min)	0.0 l m^{-2}	0.05 l m^{-2}	0.10 l m^{-2}
2.00	252.48	127.98	82.32
4.00	248.34	127.50	81.78
6.00	241.74	123.06	79.38
8.00	240.06	123.06	78.60
10.00	237.36	121.38	77.64
12.00	236.64	119.64	76.68
15.00	235.38	118.86	75.84
18.00	232.50	117.84	75.54
21.00	230.88	117.36	74.58
25.00	227.22	116.58	74.10
30.00	224.58	116.04	73.74

Table 5.11: Effect of Aq1 on Saturated Hydraulic Conductivity of Druridge Bay Sand.

Time	Saturated Hydraulic Conductivity (cm hr^{-1})			
		Aq1 Concentrations*		
(min)	0.0%	0.33%	0.50%	0.66%
2.00	252.48	144.06	108.90	105.00
4.00	248.34	141.18	106.74	101.58
6.00	241.74	138.72	105.72	101.10
8.00	240.06	138.00	104.04	99.90
10.00	237.36	135.78	102.78	99.42
12.00	236.64	135.78	102.54	98.40
15.00	235.38	134.64	101.76	97.50
18.00	232.50	133.68	100.80	96.54
21.00	230.88	133.20	100.62	95.70
25.00	227.22	131.88	99.78	94.98
30.00	224.58	131.40	99.12	94.56

* All (%) are on the base of air-dry sand.

Table 5.12: Effect of Aq2 on Saturated Hydraulic Conductivity of Druridge Bay Sand.

Time	Saturated Hydraulic Conductivity (cm hr^{-1})		
	Aq2 Concentrations		
(min)	0.0 gm m^{-2}	200 gm m^{-2}	250 gm m^{-2}
2.00	252.48	120.88	61.54
4.00	248.34	118.68	61.10
6.00	241.74	117.22	60.81
8.00	240.06	116.78	60.81
10.00	237.36	116.48	60.81
12.00	236.64	116.48	60.81
15.00	235.38	116.24	60.56
18.00	232.50	116.24	60.56
21.00	230.88	116.24	60.56
25.00	227.22	116.23	60.55
30.00	224.58	116.19	60.51

Table 5.13: Effect of PVA1 on the Intrinsic Permeability of Druridge Bay Sand.

Time	Intrinsic Permeability (cm^2) x 10^{-7}			
	PVA1 Concentrations*			
(min)	0.0%	0.1%	0.2%	0.4%
2.0	7.156	7.337	8.085	8.653
4.0	7.039	7.185	8.043	8.480
6.0	6.852	6.991	7.855	8.389
8.0	6.804	6.798	7.704	8.306
10.0	6.728	6.748	7.544	8.099
12.0	6.707	6.748	7.454	7.981
15.0	6.672	6.668	7.315	7.821
18.0	6.590	6.612	7.291	7.752
21.0	6.544	6.558	7.175	7.716
25.0	6.440	6.497	7.043	7.590
30.0	6.366	6.427	6.922	7.587

* All (%) are on the base of air-dry sand.

Table 5.14: Effect of PVA2 on the Intrinsic Permeability of Druridge Bay Sand.

Time	Intrinsic Permeability (cm^2) x 10^{-7} PVA2 Concentrations*			
(min)	0.0%	0.1%	0.2%	0.4%
2.0	7.156	7.787	8.514	8.430
4.0	7.039	7.476	8.306	8.236
6.0	6.852	7.316	8.099	7.995
8.0	6.804	7.129	7.995	7.939
10.0	6.728	7.046	7.704	7.774
12.0	6.707	6.888	7.565	7.621
15.0	6.672	6.806	7.401	7.536
18.0	6.590	6.798	7.342	7.526
21.0	6.544	6.719	7.291	7.485
25.0	6.440	6.621	7.160	7.457
30.0	6.366	6.515	7.094	7.389

Table 5.15: Effect of PEG3 on the Intrinsic Permeability of Druridge Bay Sand.

Time	Intrinsic Permeability (cm^2) x 10^{-7} PEG3 Concentrations*			
(min)	0.0%	0.1%	0.2%	0.4%
2.0	7.156	7.420	7.855	7.821
4.0	7.039	7.253	7.600	7.731
6.0	6.852	7.095	7.454	7.524
8.0	6.804	6.942	7.323	7.267
10.0	6.728	6.762	7.219	7.219
12.0	6.707	6.714	7.136	7.143
15.0	6.672	6.599	7.060	7.083
18.0	6.590	6.585	6.995	7.075
21.0	6.544	6.515	6.935	6.991
25.0	6.440	6.403	6.832	6.939
30.0	6.366	6.301	6.786	6.866

* All (%) are on the base of air-dry sand.

Table 5.16: Effect of PEG4 on the Intrinsic Permeability of Druridge Bay Sand.

Time (min)	Intrinsic Permeability (cm^2) x 10^{-7} PEG4 Concentrations* 0.0%	0.1%	0.2%	0.4%
2.0	7.156	7.738	7.871	8.457
4.0	7.039	7.670	7.760	8.223
6.0	6.852	7.580	7.628	8.168
8.0	6.804	7.503	7.517	8.092
10.0	6.728	7.427	7.386	8.065
12.0	6.707	7.344	7.316	8.015
15.0	6.672	7.323	7.267	7.942
18.0	6.590	7.304	7.207	7.867
21.0	6.544	7.240	7.199	7.776
25.0	6.440	7.216	7.167	7.667
30.0	6.366	7.094	7.133	7.561

* All (%) are on the base of air-dry sand.

Table 5.17: Effect of B.E. on the Intrinsic Permeability of Druridge Bay Sand.

Time (min)	Intrinsic Permeability (cm^2) x 10^{-7} B.E. Concentrations 0.0 l m^{-2}	0.5 l m^{-2}	1.0 l m^{-2}	1.5 l m^{-2}
2.0	7.156	6.078	2.929	1.418
4.0	7.039	5.952	2.859	1.418
6.0	6.852	5.912	2.852	1.405
8.0	6.804	5.815	2.818	1.405
10.0	6.728	5.765	2.706	1.398
12.0	6.707	5.704	2.651	1.398
15.0	6.672	5.680	2.602	1.357
18.0	6.590	5.629	2.575	1.352
21.0	6.544	5.607	2.543	1.333
25.0	6.440	5.558	2.491	1.311
30.0	6.366	5.537	2.456	1.296

Table 5.18: Effect of F.E. on the Intrinsic Permeability of Druridge Bay Sand.

Time (min)	Intrinsic Permeability (cm^2) x 10^{-7} F.E. Concentrations		
	0.0 l m^{-2}	0.2 l m^{-2}	0.4 l m^{-2}
2.0	7.156	2.063	1.939
4.0	7.039	2.049	1.889
6.0	6.852	2.007	1.889
8.0	6.804	2.000	1.849
10.0	6.728	1.993	1.849
12.0	6.707	1.980	1.813
15.0	6.672	1.974	1.804
18.0	6.590	1.961	1.804
21.0	6.544	1.942	1.791
25.0	6.440	1.920	1.782
30.0	6.366	1.888	1.764

Table 5.19: Effect of V1 on the Intrinsic Permeability of Druridge Bay Sand.

Time (min)	Intrinsic Permeability (cm^2) x 10^{-7} V1 Concentrations		
	0.0 l m^{-2}	0.05 l m^{-2}	0.10 l m^{-2}
2.0	7.156	1.939	1.267
4.0	7.039	1.883	1.253
6.0	6.852	1.820	1.253
8.0	6.804	1.820	1.253
10.0	6.728	1.772	1.247
12.0	6.707	1.772	1.240
15.0	6.672	1.745	1.231
18.0	6.590	1.740	1.223
21.0	6.544	1.716	1.199
25.0	6.440	1.702	1.194
30.0	6.366	1.685	1.187

Table 5.20: Effect of V2 on the Intrinsic Permeability of Druridge Bay Sand.

Time (min)	Intrinsic Permeability (cm^2) x 10^{-7} V2 Concentrations		
	0.0 l m^{-2}	0.05 l m^{-2}	0.10 l m^{-2}
2.0	7.156	2.117	1.675
4.0	7.039	2.070	1.662
6.0	6.852	2.036	1.641
8.0	6.804	2.020	1.571
10.0	6.728	1.986	1.565
12.0	6.707	1.980	1.558
15.0	6.672	1.961	1.537
18.0	6.590	1.952	1.532
21.0	6.544	1.920	1.527
25.0	6.440	1.889	1.522
30.0	6.366	1.872	1.512

Table 5.21: Effect of V3 on the Intrinsic Permeability of Druridge Bay Sand.

Time (min)	Intrinsic Permeability (cm^2) x 10^{-7} V3 Concentrations		
	0.0 l m^{-2}	0.05 l m^{-2}	0.10 l m^{-2}
2.0	7.156	3.628	2.333
4.0	7.039	3.614	2.318
6.0	6.852	3.488	2.250
8.0	6.804	3.488	2.228
10.0	6.728	3.440	2.201
12.0	6.707	3.391	2.173
15.0	6.672	3.369	2.150
18.0	6.590	3.340	2.141
21.0	6.544	3.327	2.114
25.0	6.440	3.304	2.100
30.0	6.366	3.289	2.090

Table 5.22: Effect of Aq1 on the Intrinsic Permeability of Druridge Bay Sand.

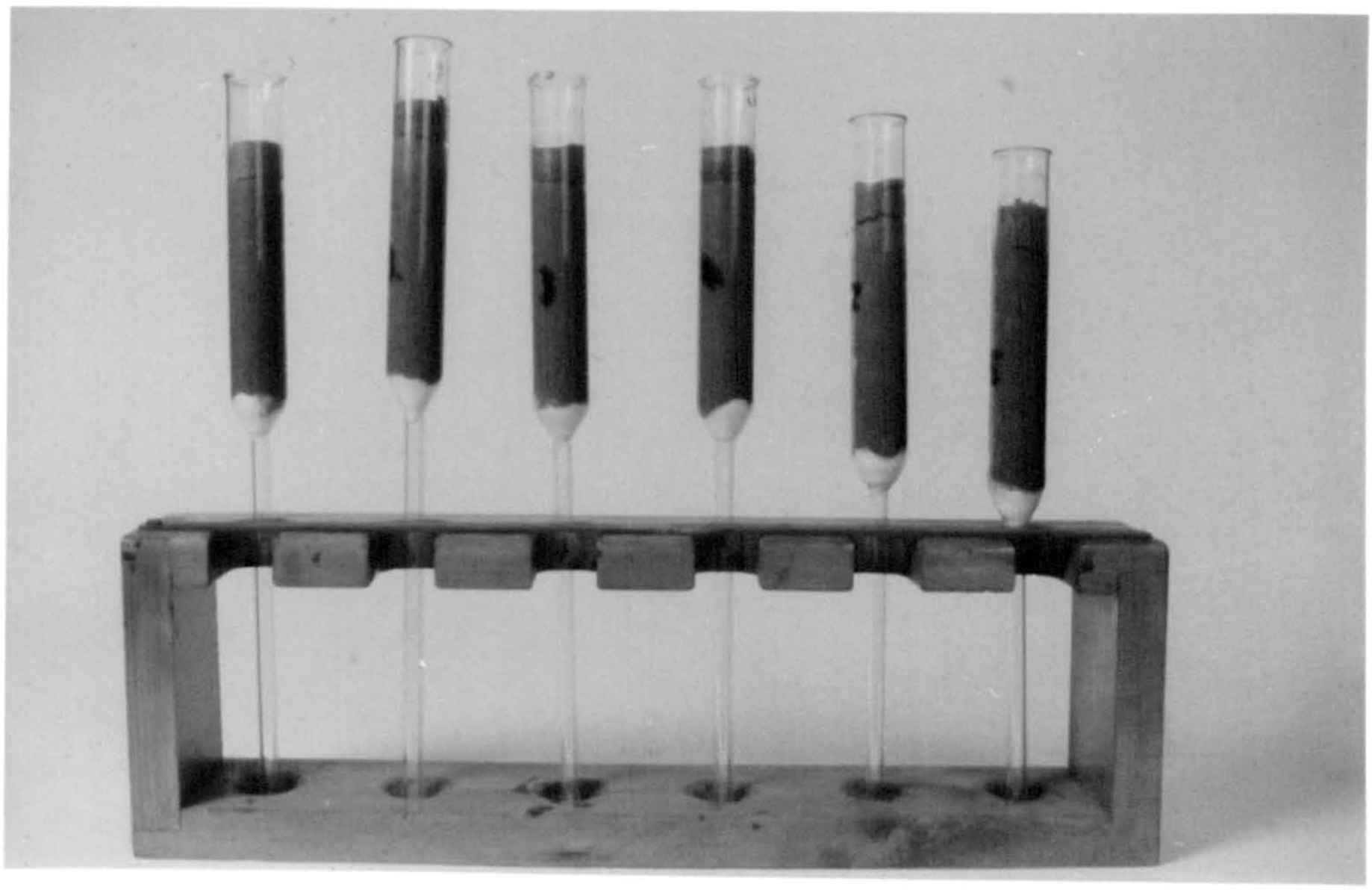
Time	Intrinsic Permeability (cm^2) x 10^{-7}			
	Aq1 Concentrations*			
(min)	0.0%	0.33%	0.50%	0.66%
2.0	7.156	4.083	3.087	2.976
4.0	7.039	4.002	3.026	2.879
6.0	6.852	3.932	2.997	2.866
8.0	6.804	3.912	2.949	2.832
10.0	6.728	3.849	2.913	2.818
12.0	6.707	3.849	2.906	2.789
15.0	6.672	3.816	2.884	2.764
18.0	6.590	3.789	2.857	2.736
21.0	6.544	3.776	2.852	2.713
25.0	6.440	3.738	2.828	2.692
30.0	6.366	3.724	2.810	2.680

* All (%) are on the base of air-dry sand.

Table 5.23: Effect of Aq2 on the Intrinsic Permeability of Druridge Bay Sand.

Time	Intrinsic Permeability (cm^2) x 10^{-7}		
	Aq2 Concentrations		
(min)	0.0 gm m^{-2}	200 gm m^{-2}	250 gm m^{-2}
2.00	7.156	3.426	1.744
4.00	7.039	3.364	1.732
6.00	6.852	3.323	1.724
8.00	6.804	3.310	1.724
10.00	6.728	3.302	1.724
12.00	6.707	3.302	1.724
15.00	6.672	3.295	1.717
18.00	6.590	3.295	1.717
21.00	6.544	3.295	1.717
25.00	6.440	3.295	1.716
30.00	6.366	3.293	1.715

Plate 5.2: Two Layers of Sand in Each Infiltration Column Due to the Reorientation and Washing Down of the Finer Sand Particles.



concentrations of the first group increases so does the hydraulic conductivity and intrinsic permeability of the sands. For the second group both properties decrease as concentration increases (table 5.24).

The increase of saturated hydraulic conductivities with the increase of the first group of chemicals agreed with the results reported by (Gabriels, 1972; Rabines Flores, 1973; and Pla, 1975). Theses increases are probably caused by an increase in the stability of the macropores within the surface layer as a result of the increase in the water stability of the treated aggregates (Gabriels, 1972). The hydraulic conductivity is greater if the soil is highly porous, fractured, or aggregated than if it is tightly compacted and dense (Hillel, 1971).

The reductions in both properties as a result of treating sand samples with the second group of chemicals, is probably due to the hydrophobic character of these materials (Gabriels, 1975).

Table 5.24: Hydraulic Conductivity and Intrinsic Permeability (Mean of Three Replicates) of Druridge Sands Treated With Various Chemical Stabilizers.

Treats	Conc.*	Hydraulic Conductivity (cm hr^{-1})	Intrinsic Permeability (cm^2) x 10^{-7}
Control	—	237.02	6.7180
PVA1	0.1%	239.17	6.7790
	0.2%	264.38	7.4937
	0.4%	283.44	8.0340
PVA2	0.1%	247.29	7.0092
	0.2%	270.92	7.6792
	0.4%	273.86	7.7625
PEG3	0.1%	239.23	6.7808
	0.2%	254.00	7.1995
	0.4%	255.49	7.2417
PEG4	0.1%	261.20	7.4035
	0.2%	261.23	4.4046
	0.4%	281.71	4.9848
B.E.	0.5 l m^{-2}	202.82	5.7488
	1.0 l m^{-2}	94.55	2.6802
	1.5 l m^{-2}	48.40	1.3719
F.E.	0.2 l m^{-2}	69.85	1.9797
	0.4 l m^{-2}	64.70	1.8339
V1	0.05 l m^{-2}	62.84	1.7813
	0.10 l m^{-2}	43.45	1.2315
V2	0.05 l m^{-2}	69.93	1.9821
	0.10 l m^{-2}	55.45	1.5729
V3	0.05 l m^{-2}	120.85	3.4253
	0.10 l m^{-2}	77.29	2.1907
Aq1	0.33%	136.21	3.8609
	0.50%	102.98	2.9190
	0.66%	98.61	2.7950
Aq2	200 gm m^{-2}	117.06	3.318
	250 gm m^{-2}	60.78	1.723

* All (%) are on the base of air-dry sand.

The reduction in both hydraulic conductivity and intrinsic permeability caused by the latter group of materials could pose potential problems for leaching and irrigation of any treated soils. However, as the figures in table (5.24) shows, the hydraulic conductivity of all samples exceeds the danger threshold of 0.1 cm hr^{-1} quoted by Richards (1969). Thus there are no difficulties or problems related to the movement of water into Druridge Bay sands treated with any of the chemical materials. It is likely that the reductions in hydraulic conductivity will reduce the leaching of the nutrient materials from the plant root zone in cultivated soils and sand dune fields.

Comparing the results in (table 5.24) with those produced by O'Neal (1952) (table 5.25), all saturated hydraulic conductivity and intrinsic permeability values of both untreated and treated samples from Druridge Bay fall within the very rapid class as the hydraulic conductivities are higher than 25 cm hr^{-1} and the intrinsic permeabilities higher than 700 x 10^{-10} cm^2.

Table 5.25 : Permeability Classes for Saturated Subsoils, and the Corresponding Ranges of Hydraulic Conductivity and Permeability (O'Neal, 1952; Cited by Klute, 1965).

Class	Hydraulic Conductivity (cm hr^{-1})	Permeability (cm^2)
Very slow	< 0.125	< 3 x 10^{-10}
Slow	0.125 - 0.50	3 x 10^{-10}- 15 x 10^{-10}
Moderately slow	0.50 - 2.00	15 x 10^{-10}- 60 x 10^{-10}
Moderate	2.00 - 6.25	60 x 10^{-10}-170 x 10^{-10}
Moderately rapid	6.25 - 12.50	170 x 10^{-10}-350 x 10^{-10}
Rapid	12.50 - 25.00	350 x 10^{-10}-700 x 10^{-10}
Very rapid	> 25.00	> 700 x 10^{-10}

5.1.3 Effect of Soil Chemical Stabilizers on the Soil Temperature

5.1.3.1 Theoretical Basis

Annual and diurnal variations in soil temperature strongly affect physical, chemical and biological processes occurring within soils (Matthias and Warrick, 1987). For example, soil temperature gradients affect the movement of water within soil profile both in vapour and liquid phases. Temperature is one of the determining factors for the germination of seeds and later on plant growth, for microbiological activities, for chemical reactions in the soil, and consequently the availability of the nutrients elements for the plant (Callebaut and De Boodt, 1981).

Soil conditioning mulches are generally thought to promote increased soil temperature (Callebaut and De Boodt, 1981). For example, Sherwood and Engibous (1953) found that, soil temperatures were frequently higher in plots treated with hydrolized polyacrylonitrile and a modified vinyl acetate maleic acid compound than in untreated soil. Kowsar et al. (1969) found that the temperature at the depth of 1 cm in a petroleum mulch-covered soil was 5^{o}C warmer than the bare one at the time the soil temperatures attained their maximum value. At all other times the temperature difference between the treated and untreated soil was less pronounced.

Saleh's (1984) studies showed that both bitumen emulsions and bitumen emulsions with latex used as mulches increased soil temperature at the depth of 5 cm, when compared with the control. Furthermore, the temperatures increased as the concentration of bitumen increased, whereas PAM and calcium lignosulfonate mulches increased soil temperature only when applied in high concentrations.

In some cases however, they can actually reduce the soil temperature depending on the height and heat reflection of the mulch. For example, Jordan and Sampson (1967) found that, although the mulched soil appeared to be warmer than bare soil throughout the springtime when the soil was wet, it was colder at

night at 1 cm depth during the summer when the soil is somewhat drier.

5.1.3.2 Techniques, Materials and Methods

As part of a duplicate on going greenhouse experiment involving the growing of either marram grass tillers or *Eucalyptus spp.* plants in pots containing 8 kg of Druridge Bay sand and treated with the various chemical stabilizers,* tempreatures were recorded at three different depths; the sand surface, 5 cm and 10 cm depths. Mercury thermometers were used to record the sand temperature, which was measured at 5, 10, 40, 65 and 85 days after the time of spraying the sand surface with the chemical materials. All measurements were taken two days after irrigation.

5.1.3.3 Results and Discussions

The greenhouse air-temperature, and the temperature of the sand samples after 5, 10, 40, 65 and 85 days from spraying, are illustrated in figures (5.34 - 5.41) and tables (5.26 - 5.31).

It is obvious from all the figures that air-temperature was the main factor controlling the sand temperature. Sand temperature at the surface and at the depths of 5 cm and 10 cm under the sand surfaces of both the untreated and treated samples increased as the air-temperature increased, and decreased as the air-temperature decreased.

In the Eucalyptus experiment, the surface temperatures for the sand mulched with B.E. (figure 5.34); F.E. (figure 5.34) and Aq1 (figure 5.37) all exceeded the control surface temperature by at least 1°C. All the other mulched surfaces varied by less than 1°C from the control. At 10 cm depth the maximum difference

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* *Aquapol 35-0031 (Aq2) was not available at the time of this experiment so no data is available fo its effect on soil temperatures.*

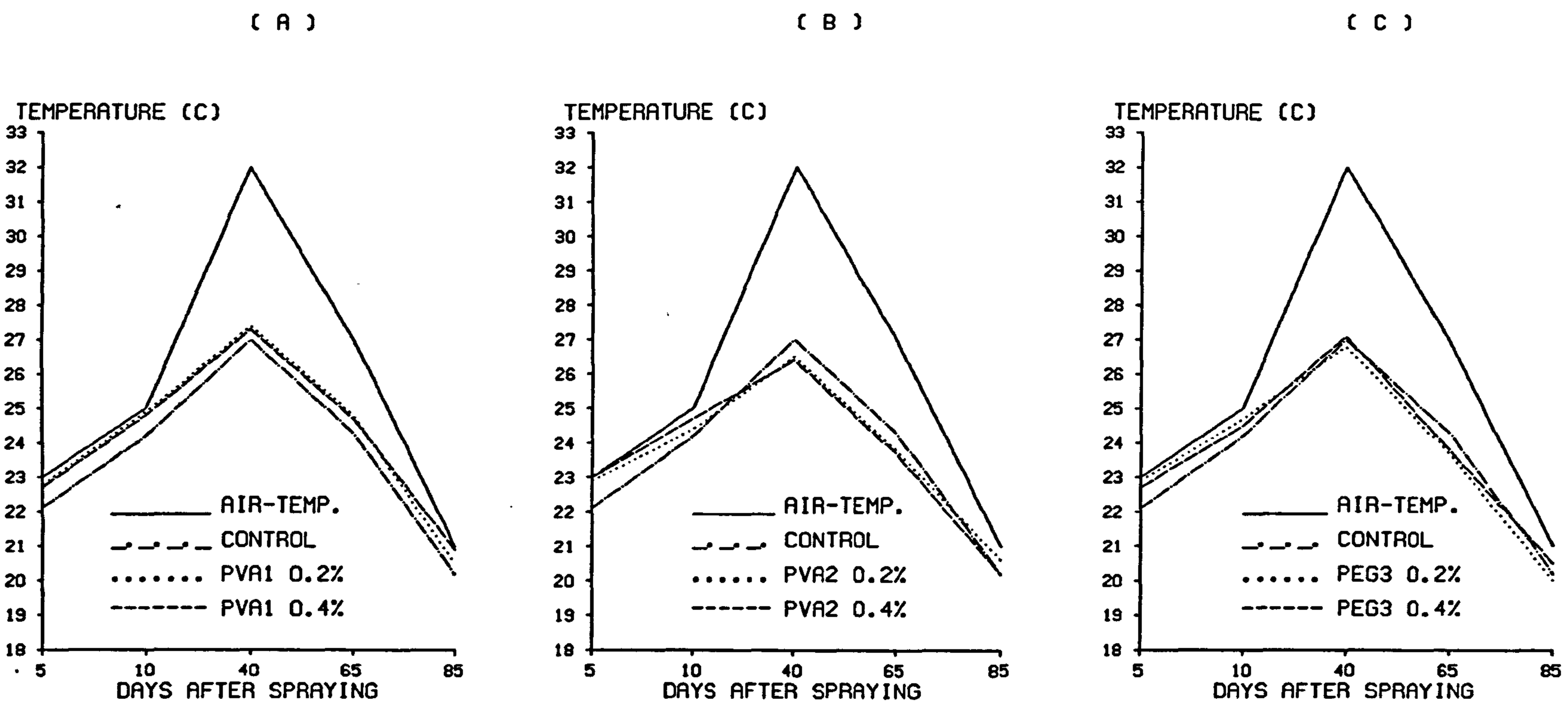
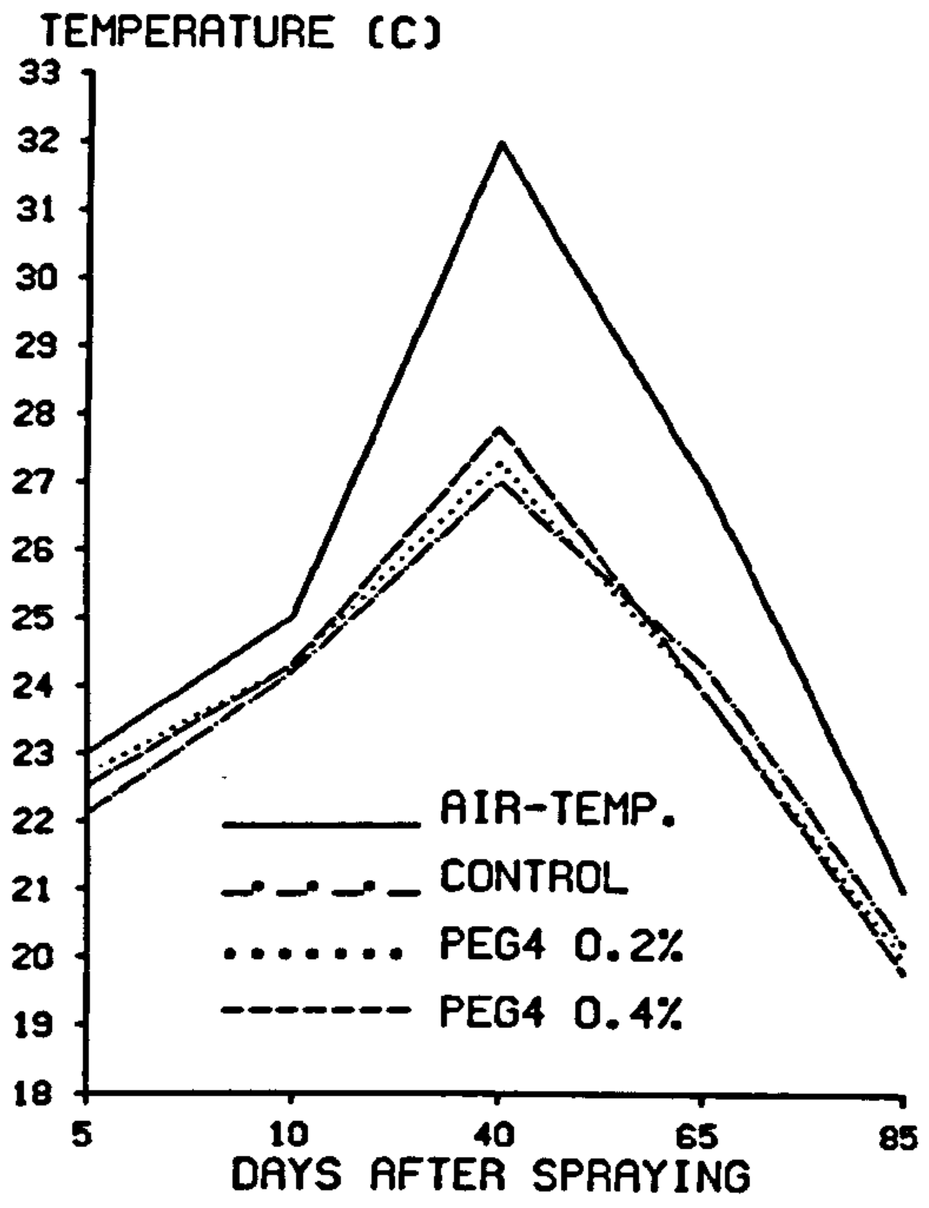
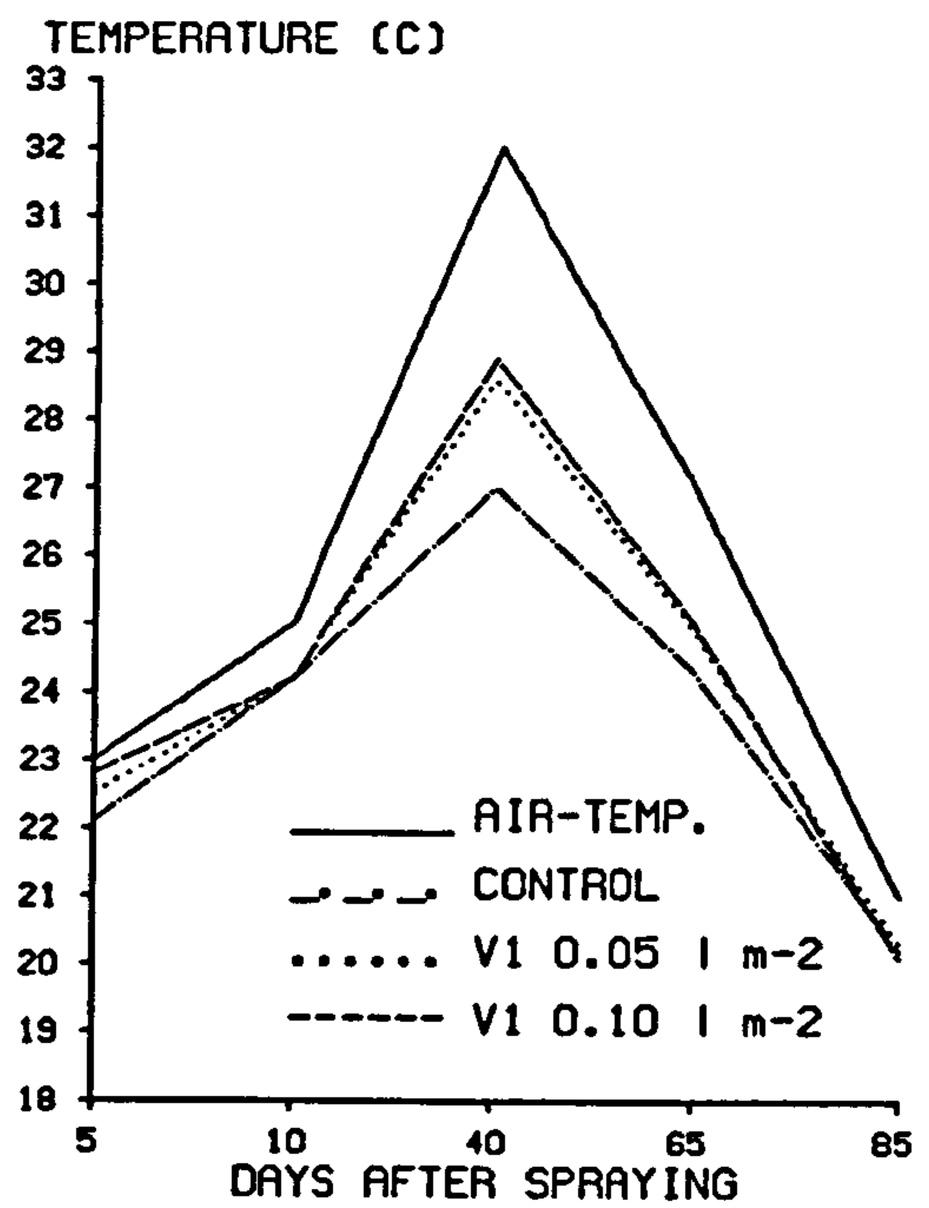


FIG. 5.34 (A - C): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE SURFACE TEMPERATURE OF DRURIDGE BAY SAND (EUCALYPTUS EXPERIMENT).

(D)



(E)



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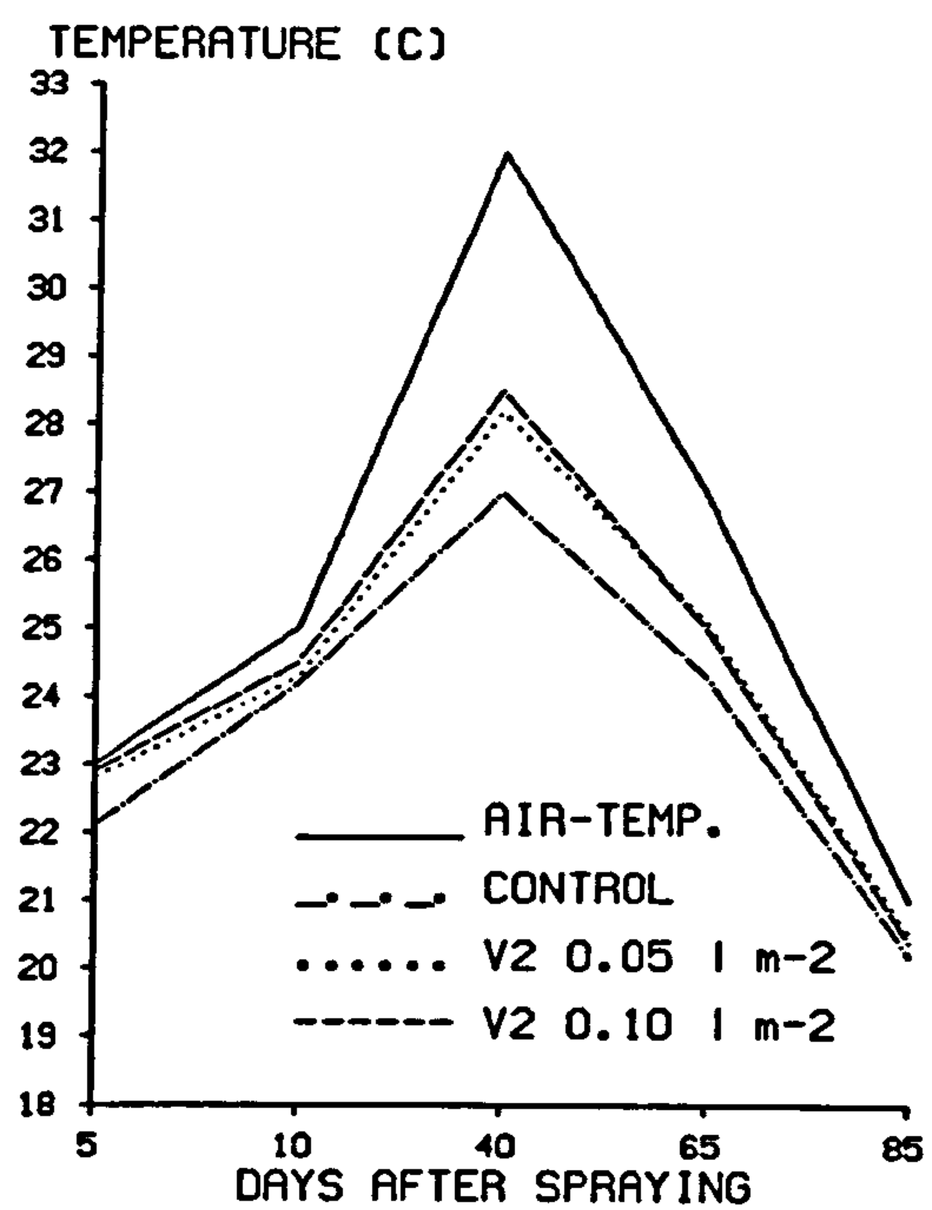


FIG. 5.34 (D - F): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE SURFACE TEMPERATURE OF DRURIDGE BAY SAND (EUCALYPTUS EXPERIMENT).

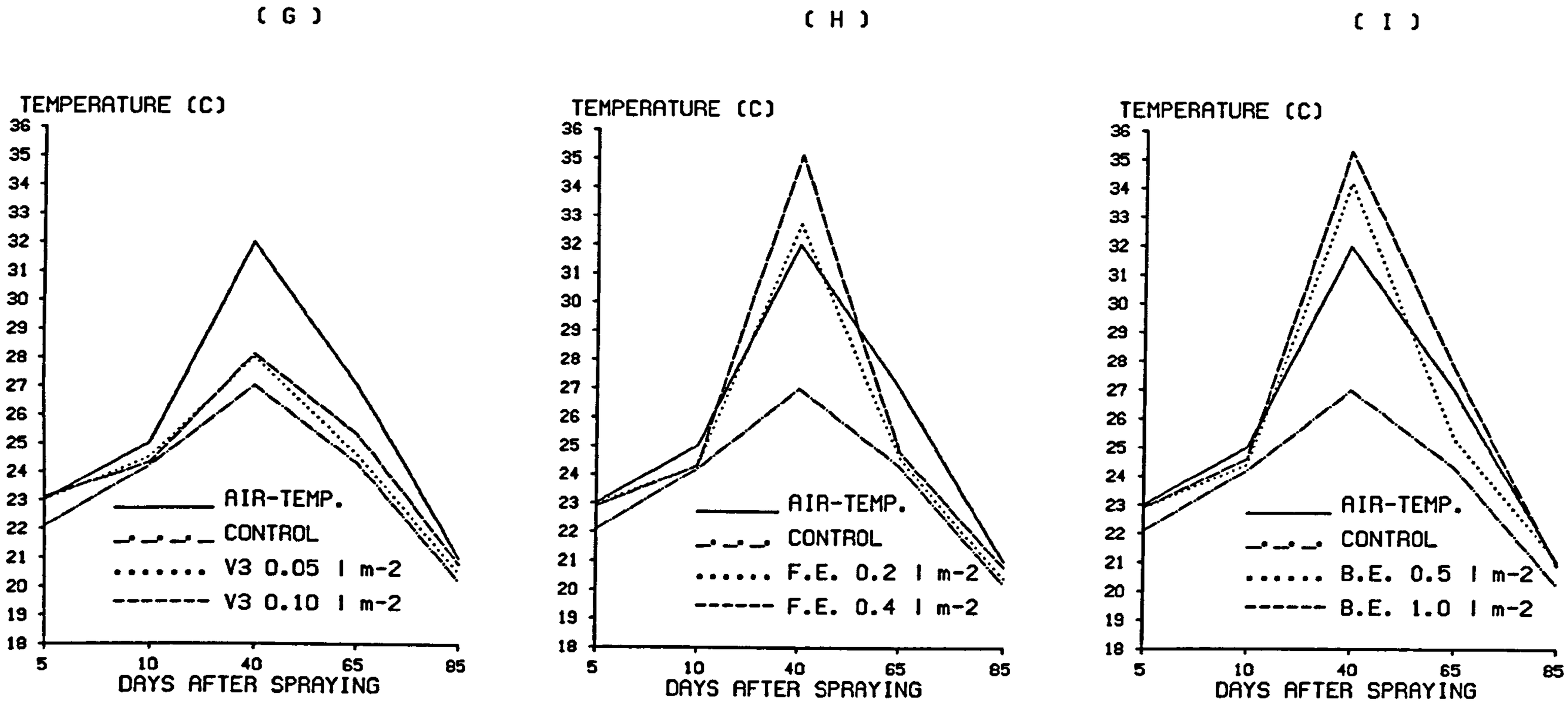


FIG. 5.34 (G - I): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE SURFACE TEMPERATURE OF DRURIDGE BAY SAND (EUCALYPTUS EXPERIMENT).

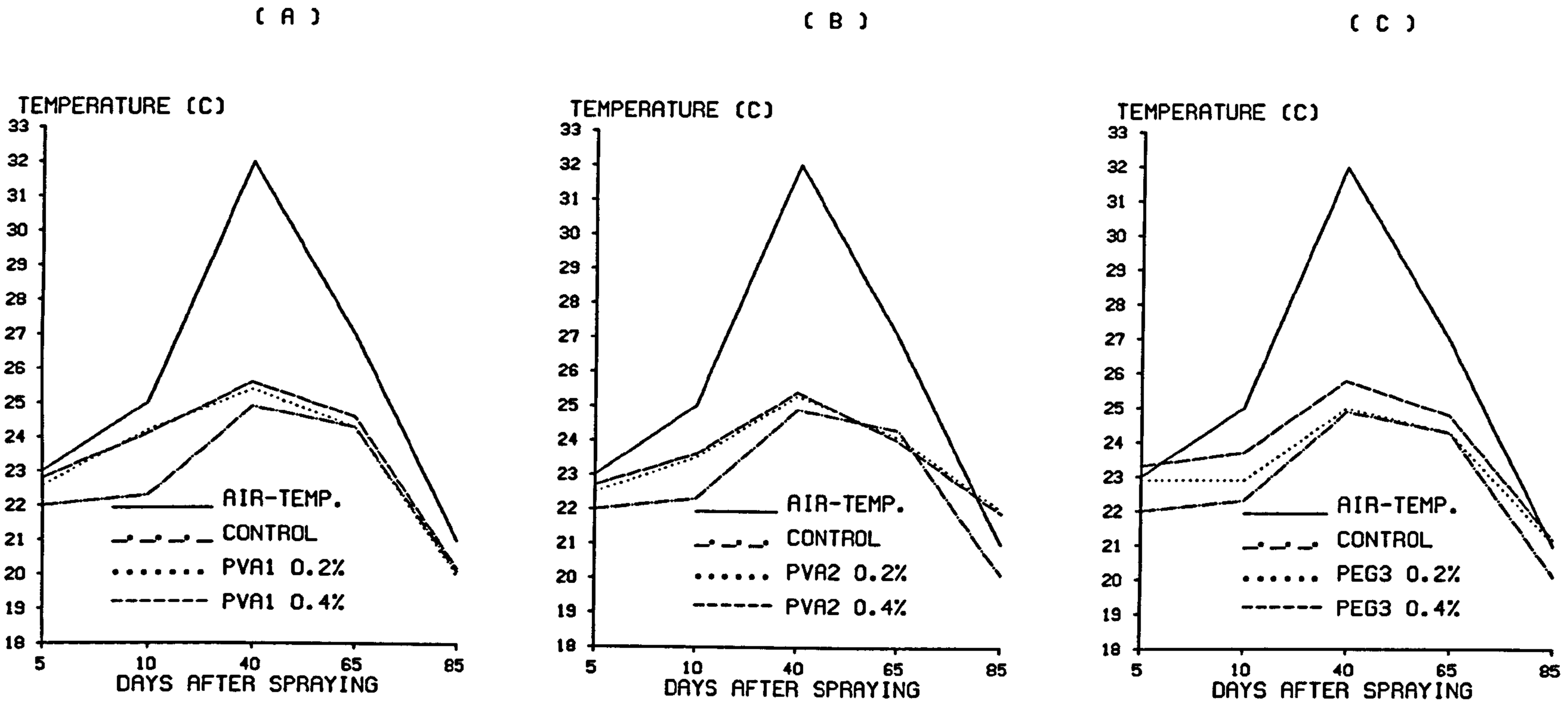
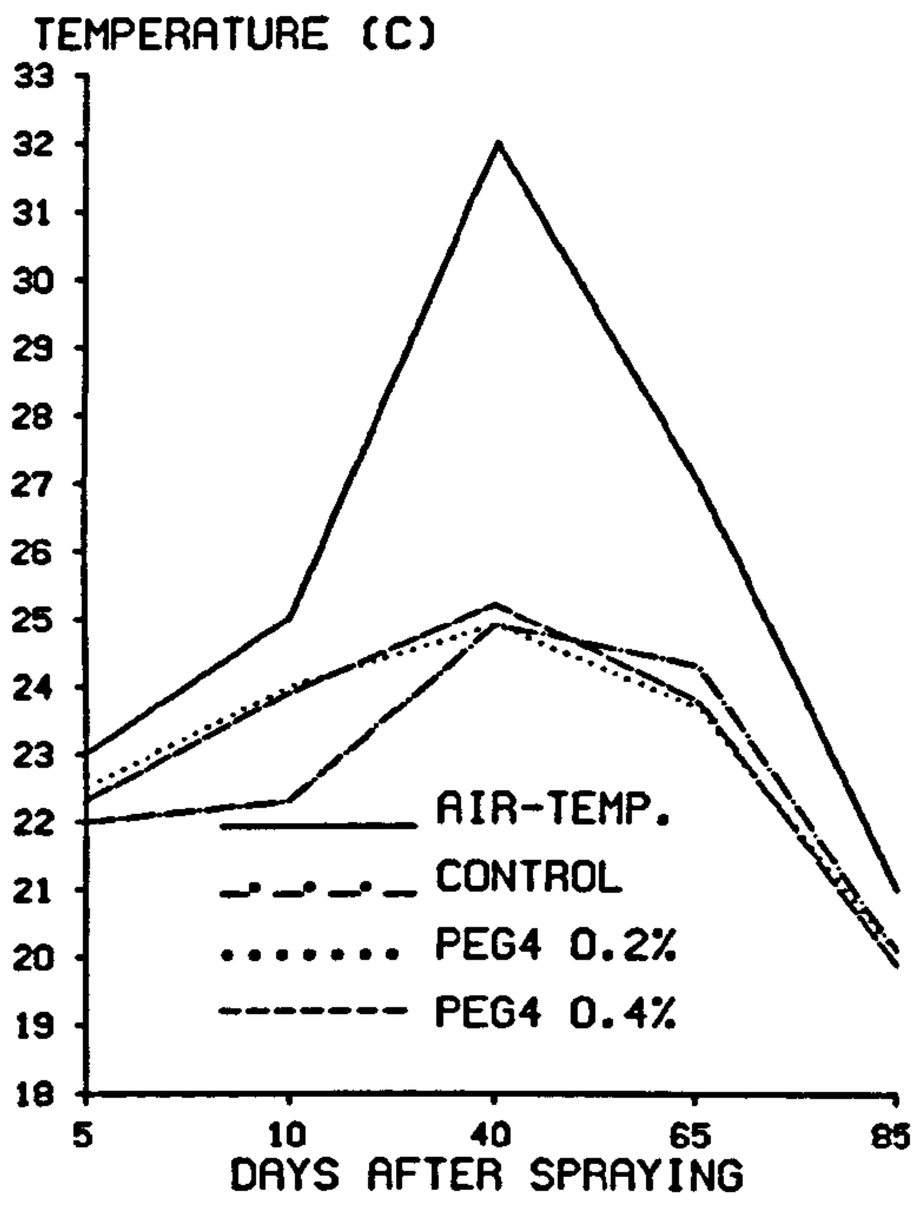


FIG. 5.35 (A - C): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE (5 cm DEPTH) TEMPERATURE OF DRURIDGE BAY SAND (EUCALYPTUS EXPERIMENT).

(D)



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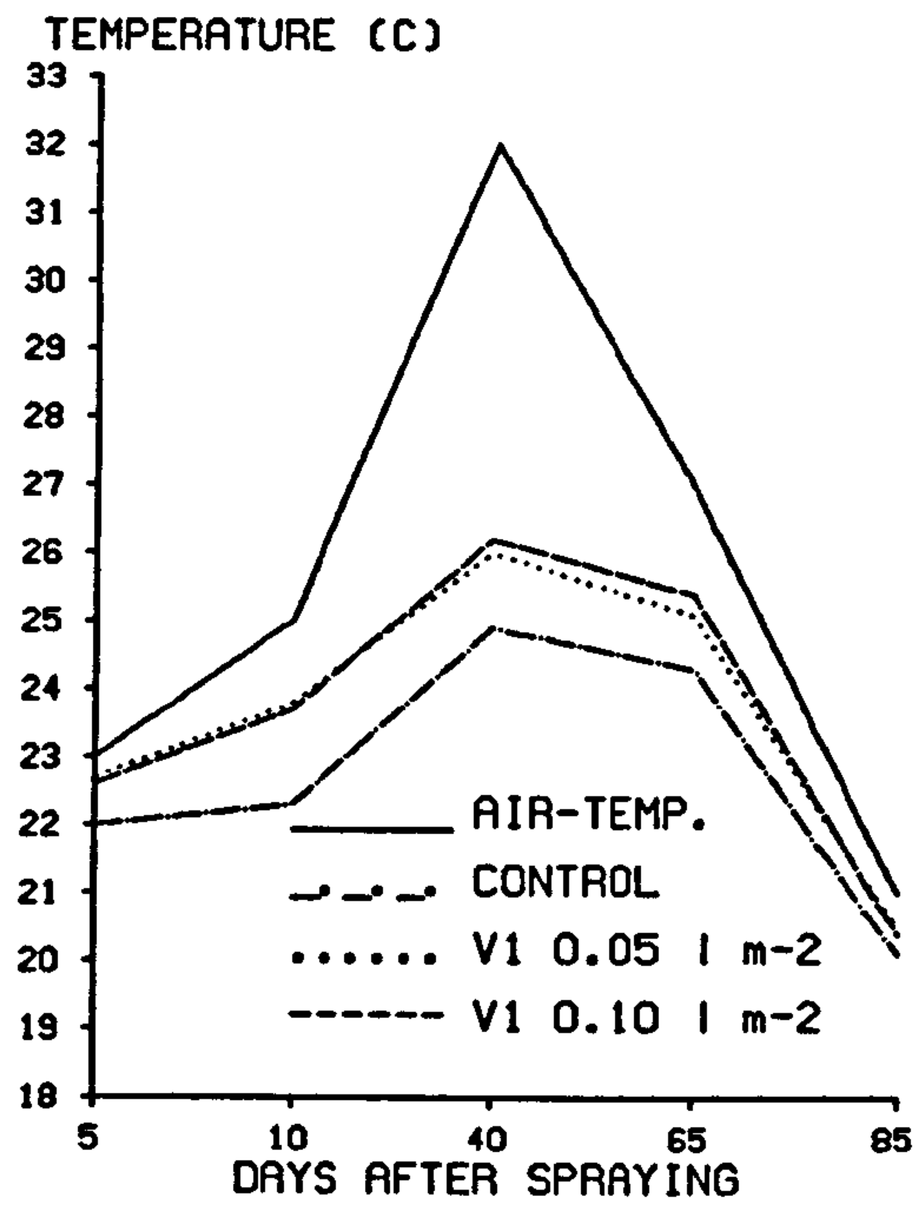

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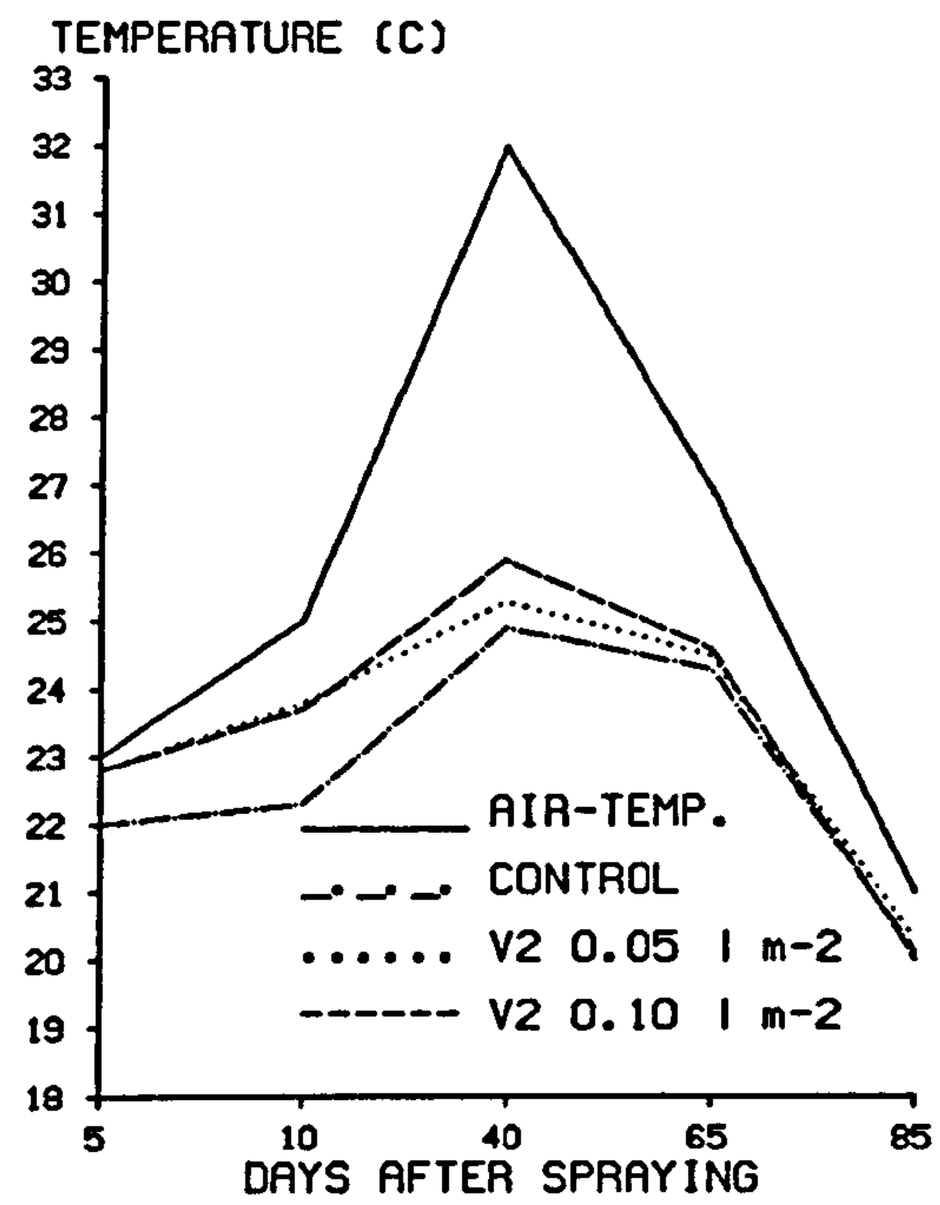
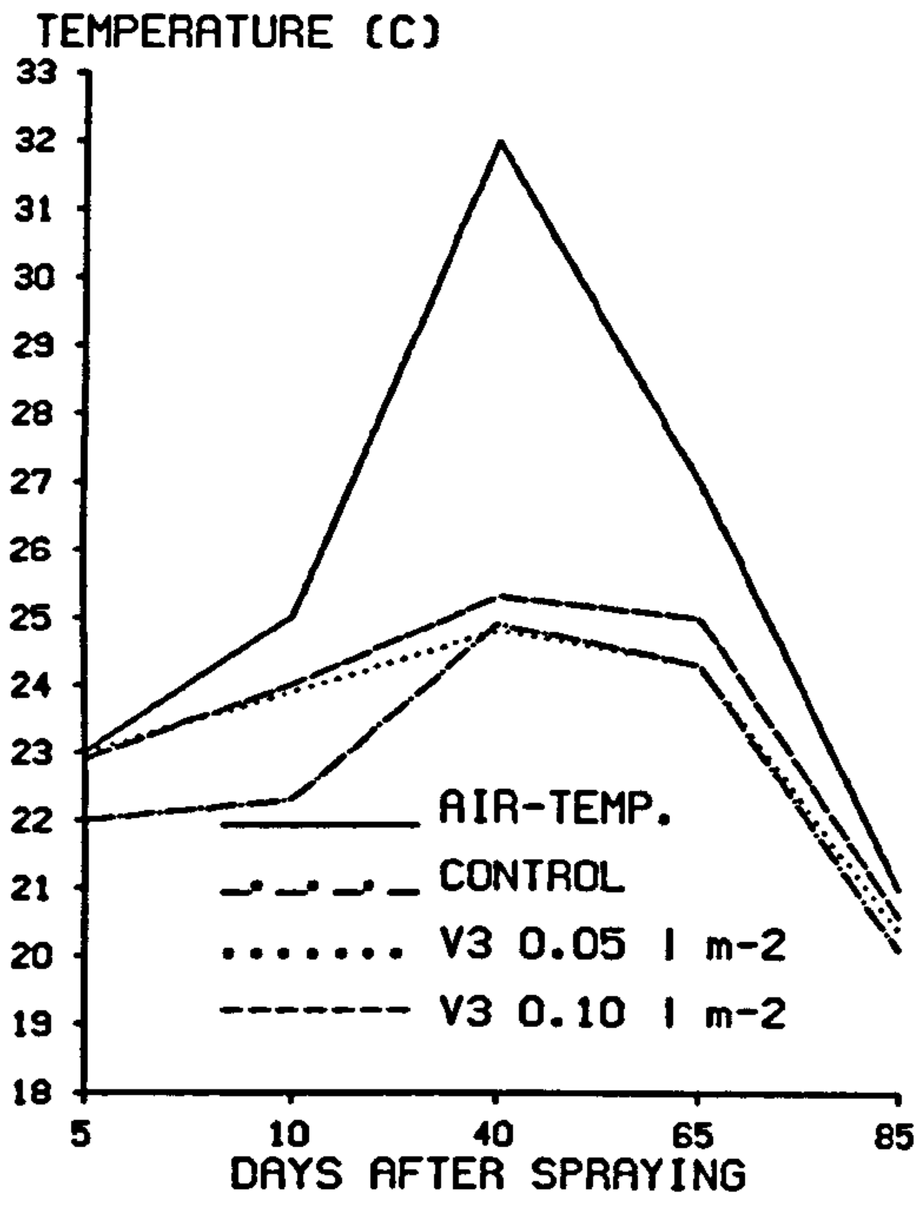
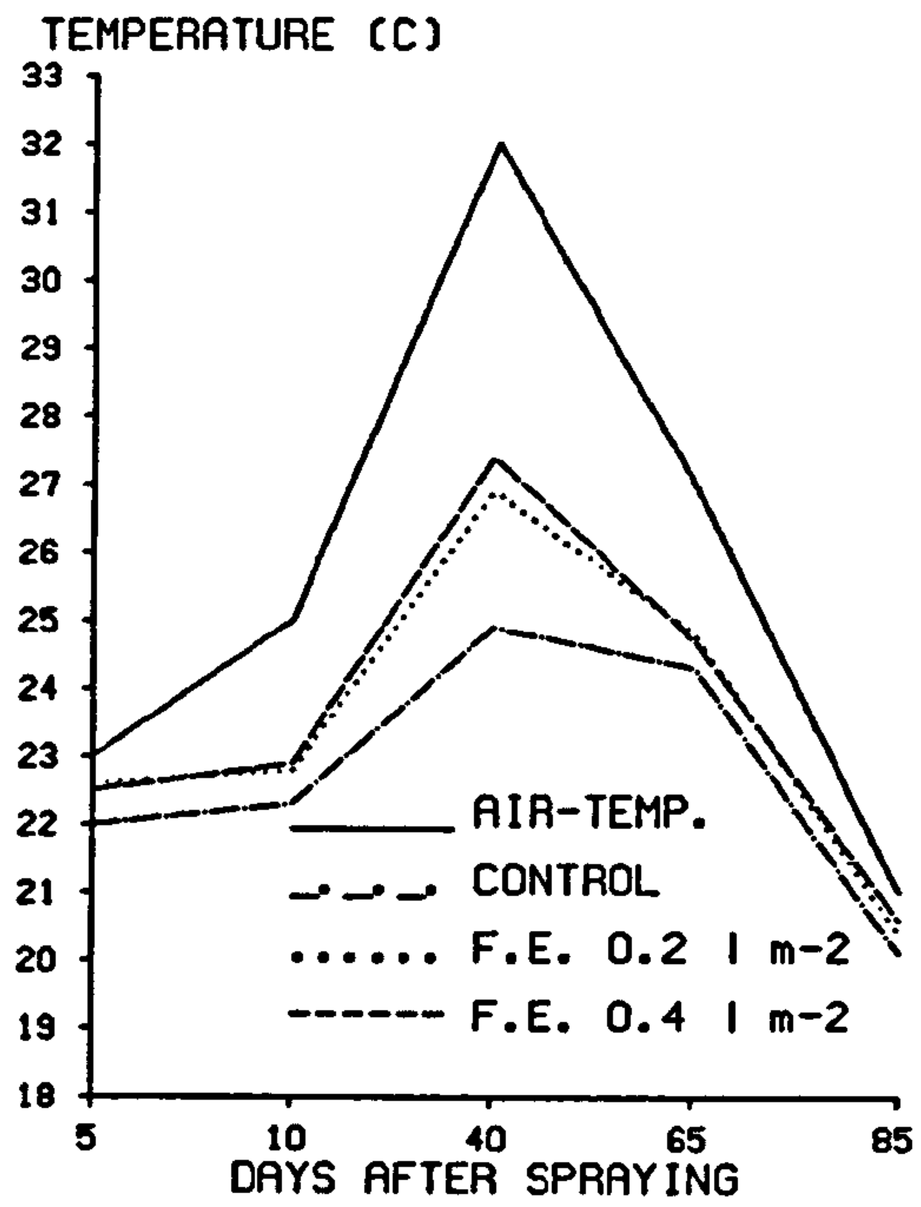


FIG. 5.35 (D - F): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE (5 cm DEPTH) TEMPERATURE OF DRURIDGE BAY SAND (EUCALYPTUS EXPERIMENT).

(G)



(H)



(I)

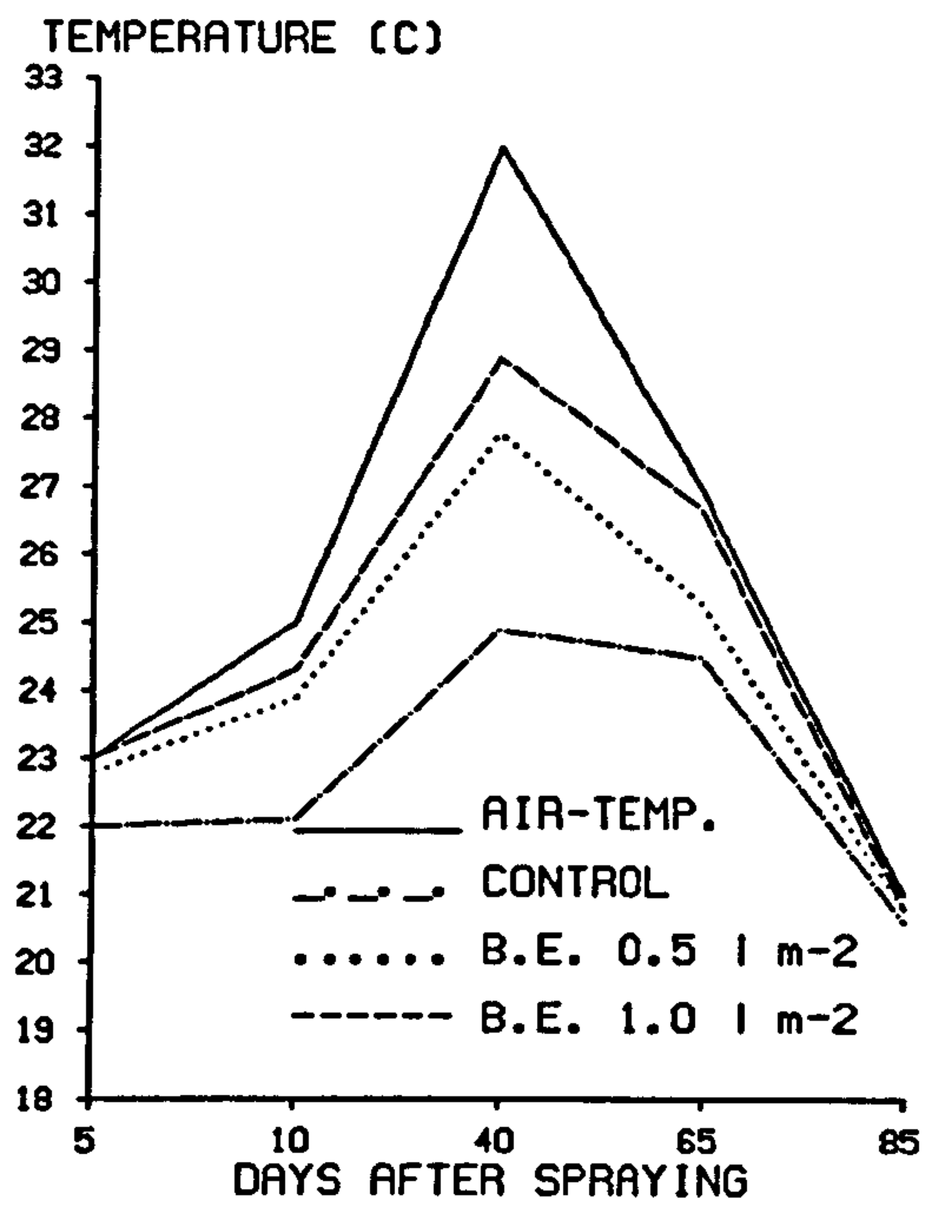


FIG. 5.35 (G - I): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE (5 cm DEPTH) TEMPERATURE OF DRURIDGE BAY SAND (EUCALYPTUS EXPERIMENT).

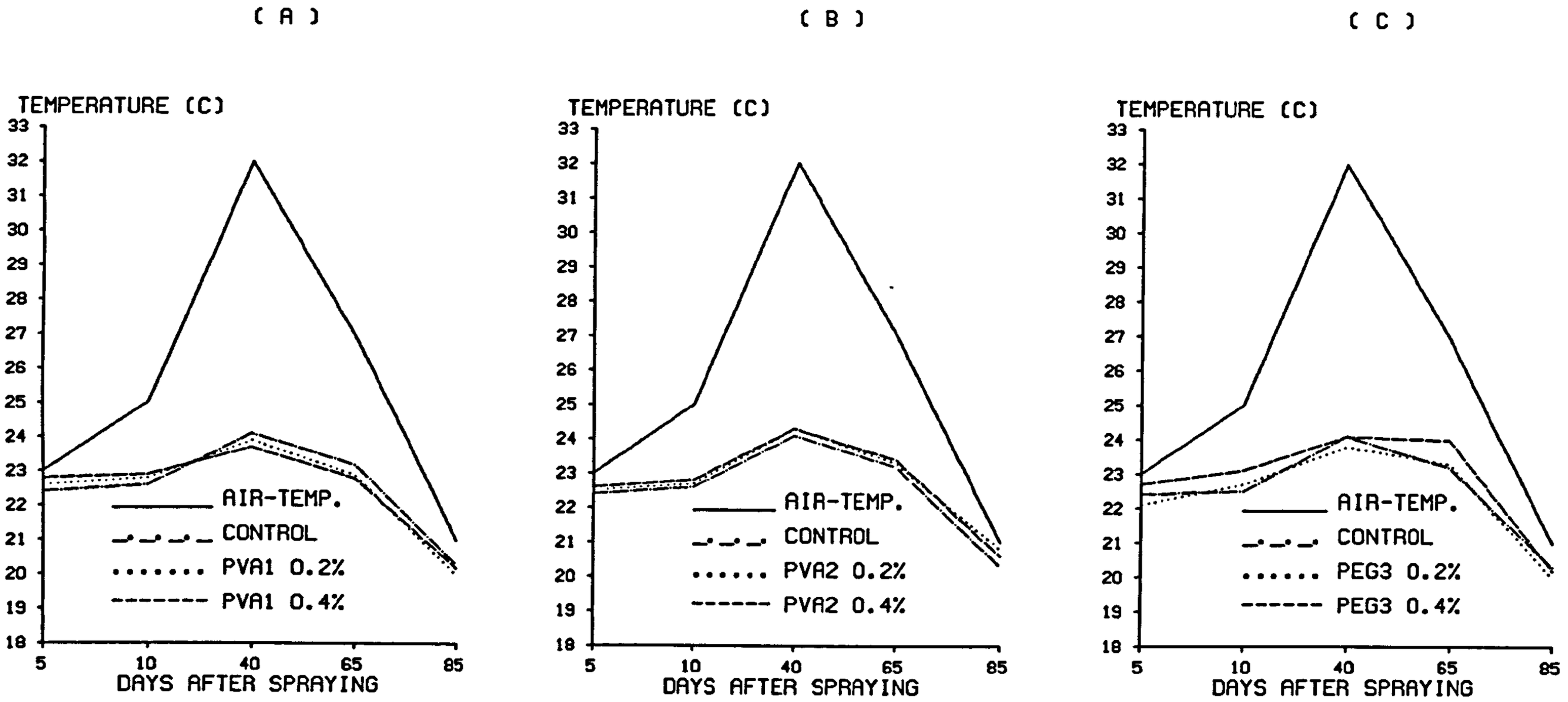


FIG. 5.36 (A - C): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE (10 cm DEPTH) TEMPERATURE OF DRURIDGE BAY SAND (EUCALYPTUS EXPERIMENT).

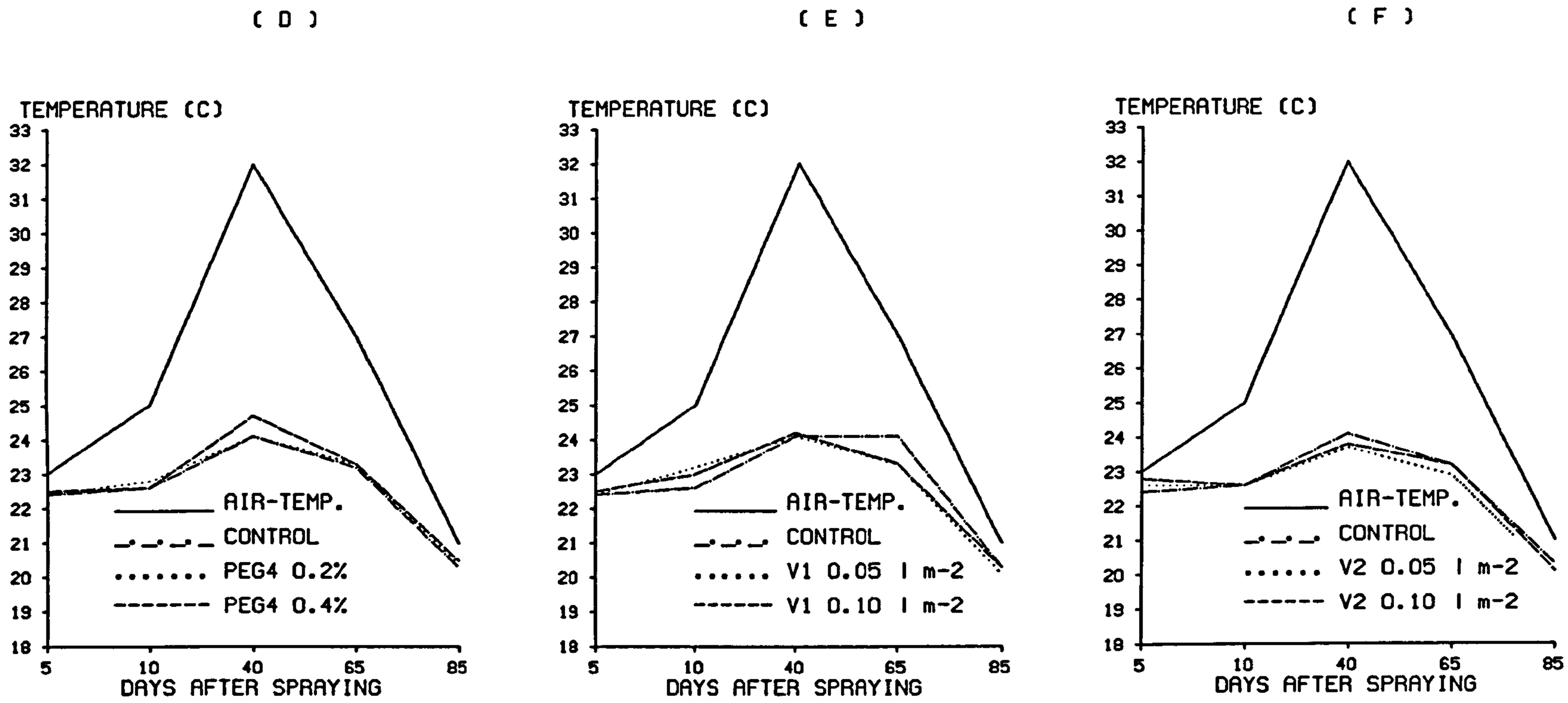
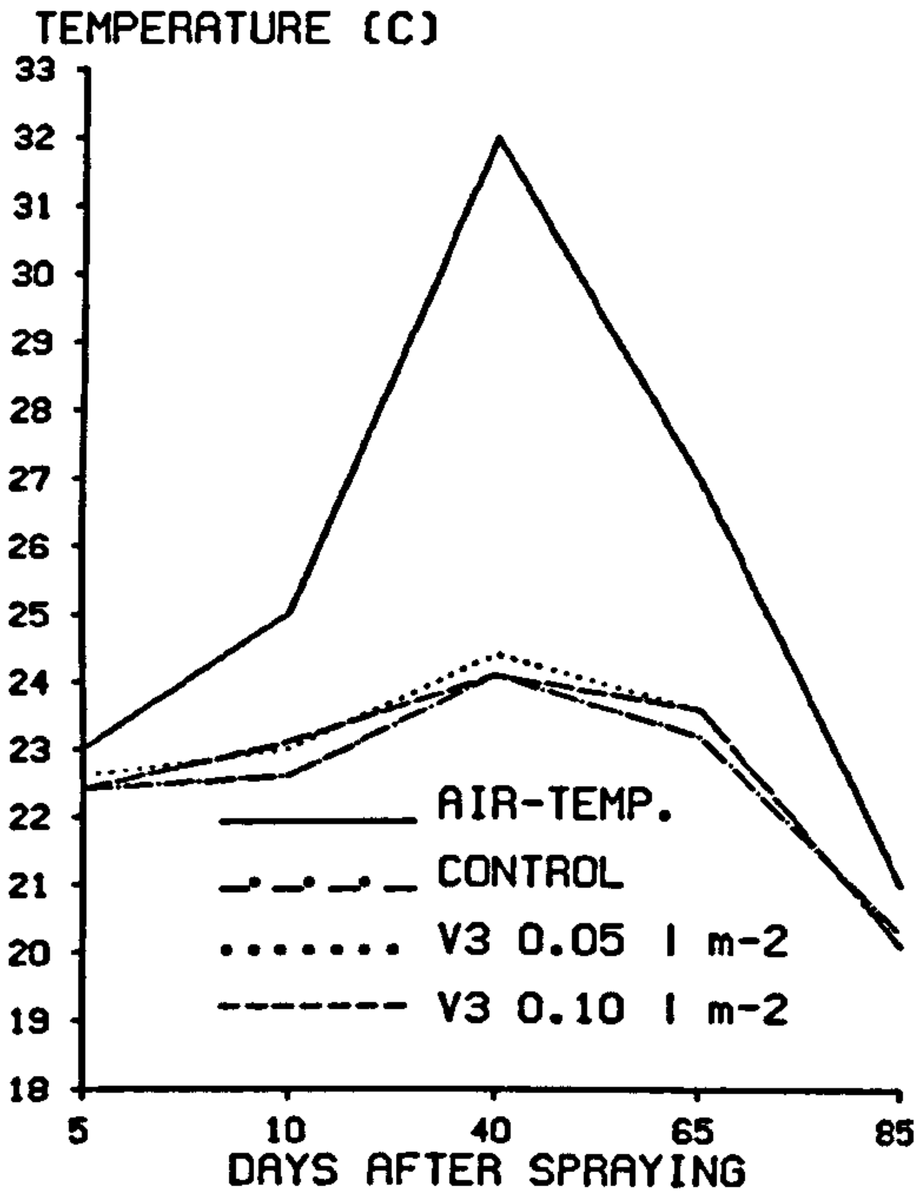
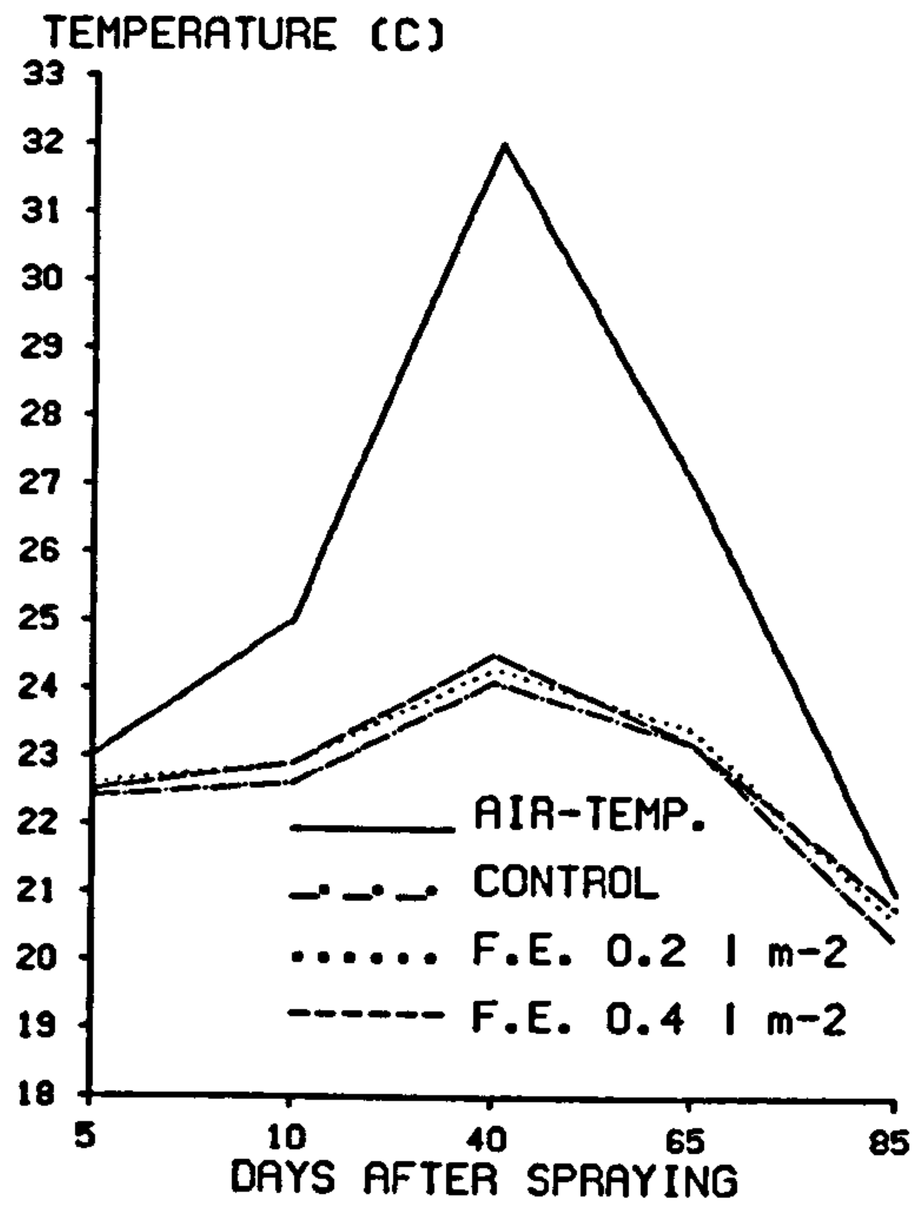


FIG. 5.36 (D - F): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE (10 cm DEPTH) TEMPERATURE OF DRURIDGE BAY SAND (EUCALYPTUS EXPERIMENT).

(G)



(H)



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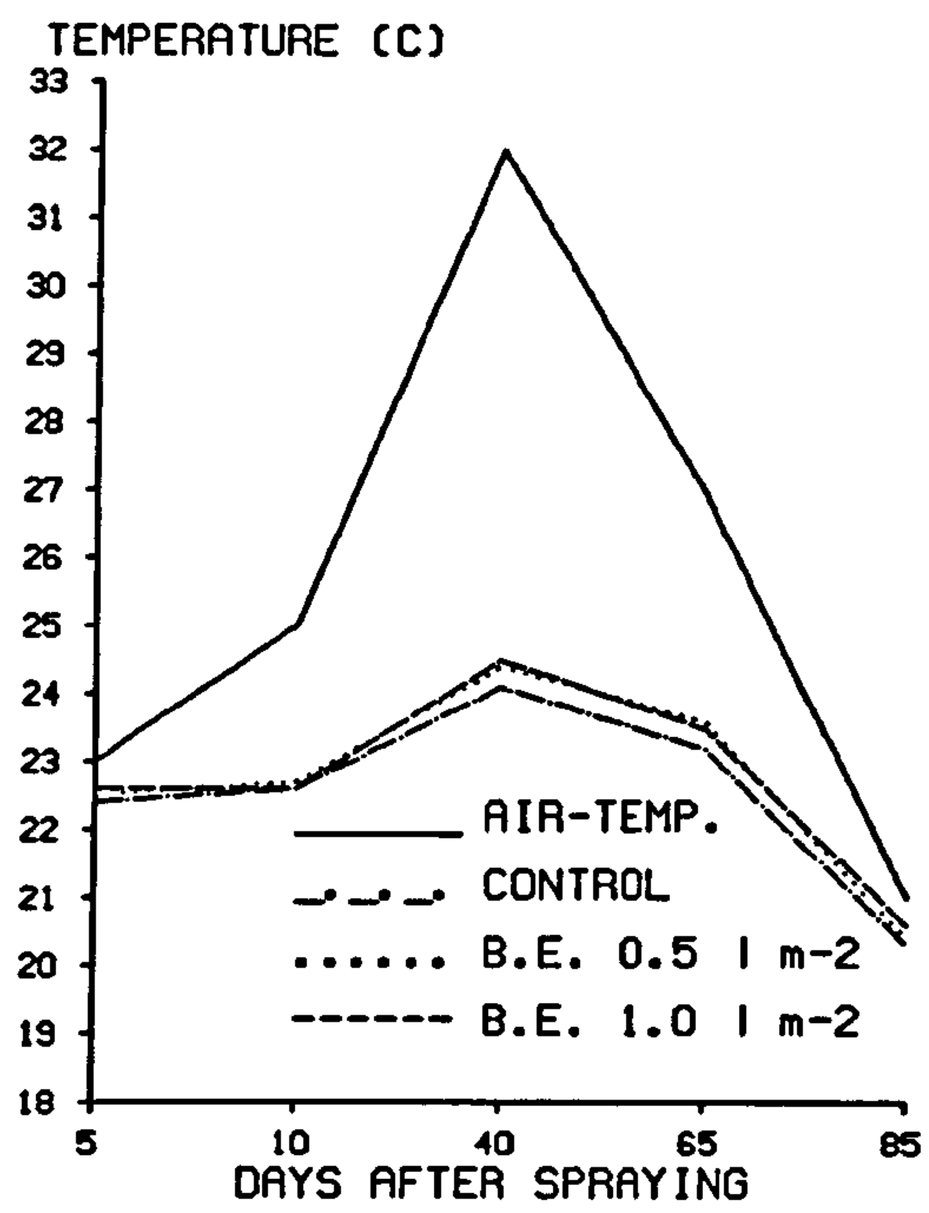


FIG. 5.36 (G - I): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE (10 cm DEPTH) TEMPERATURE OF DRURIDGE BAY SAND (EUCALYPTUS EXPERIMENT).

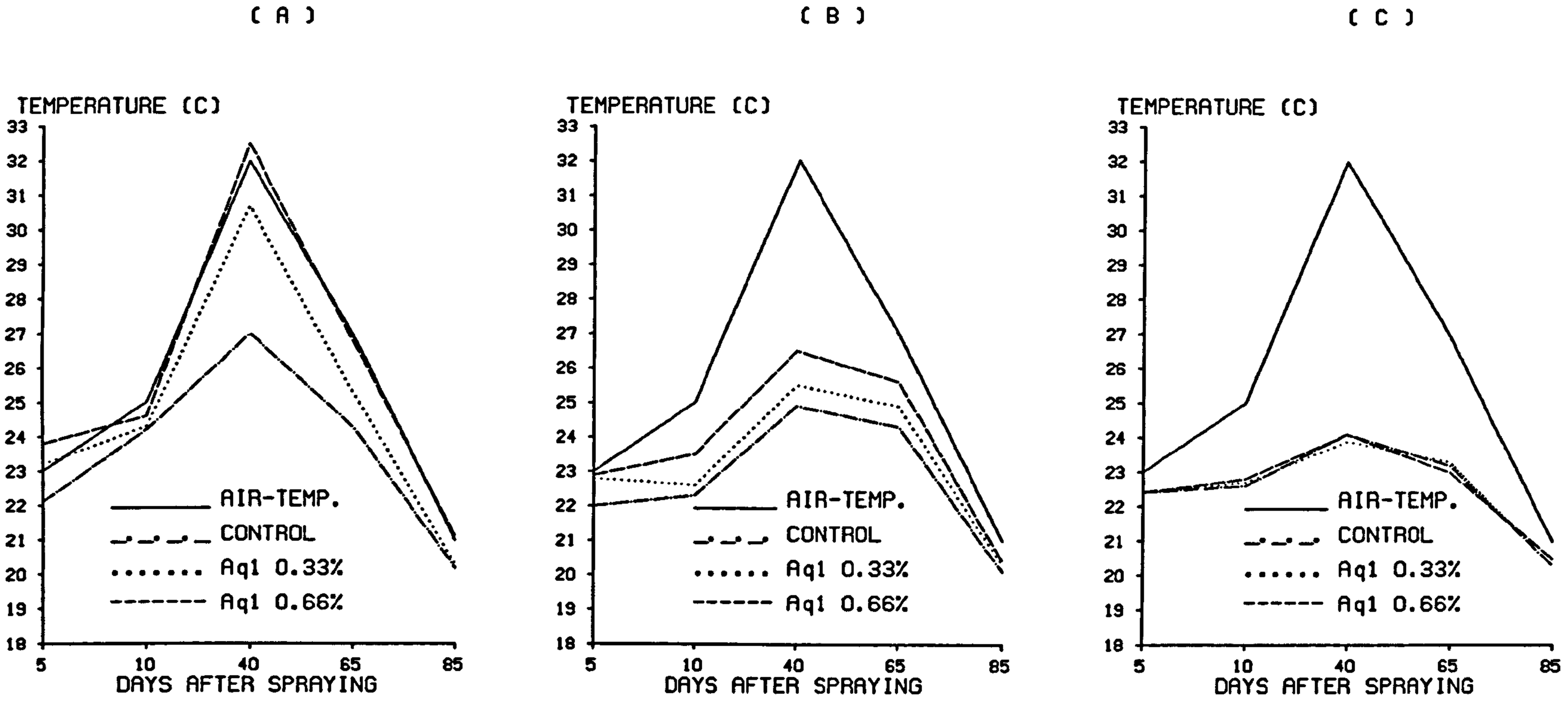


FIG. 5.37: EFFECT OF AQUAPOL 35-0019 ON THE SAND TEMPERATURE FROM DRURIDGE BAY AT THE DEPTHS: (A) SAND SURFACE; (B) 5 cm DEPTH; (C) 10 cm DEPTH (EUCALYPTUS EXPERIMENT)

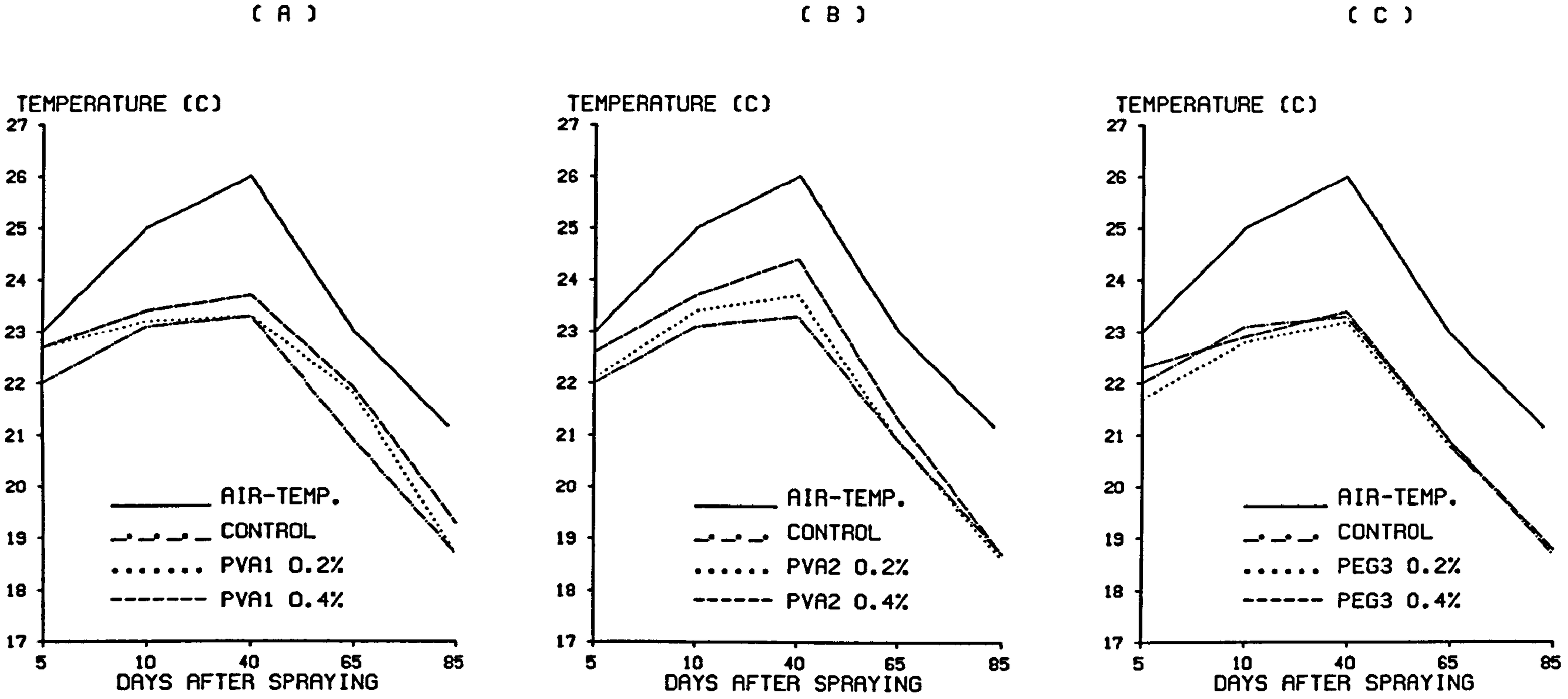


FIG. 5.38 (A - C): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE SURFACE TEMPERATURE OF DRURIDGE BAY SAND (MARRAM GRASS EXPERIMENT).

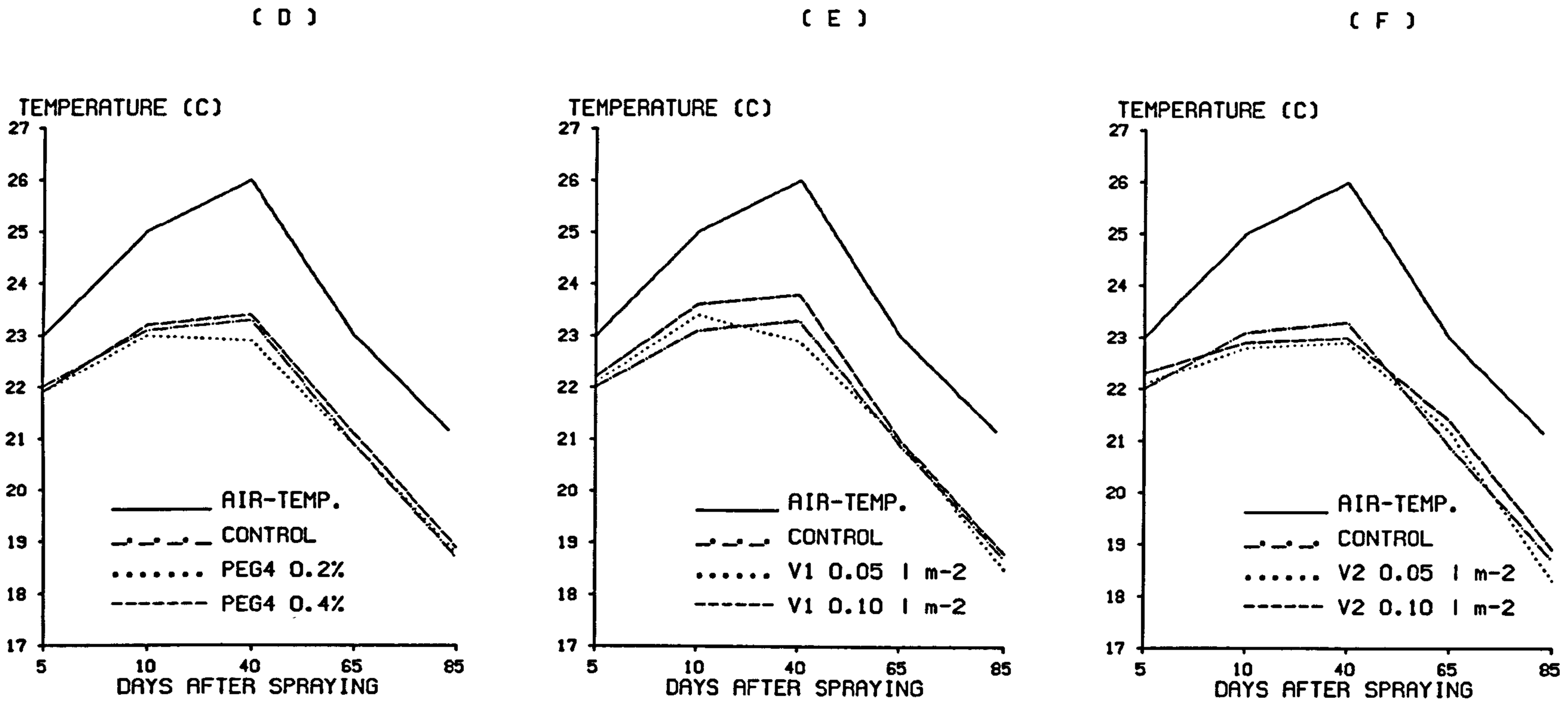


FIG. 5.38 (D - F): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE SURFACE TEMPERATURE OF DRURIDGE BAY SAND (MARRAM GRASS EXPERIMENT).

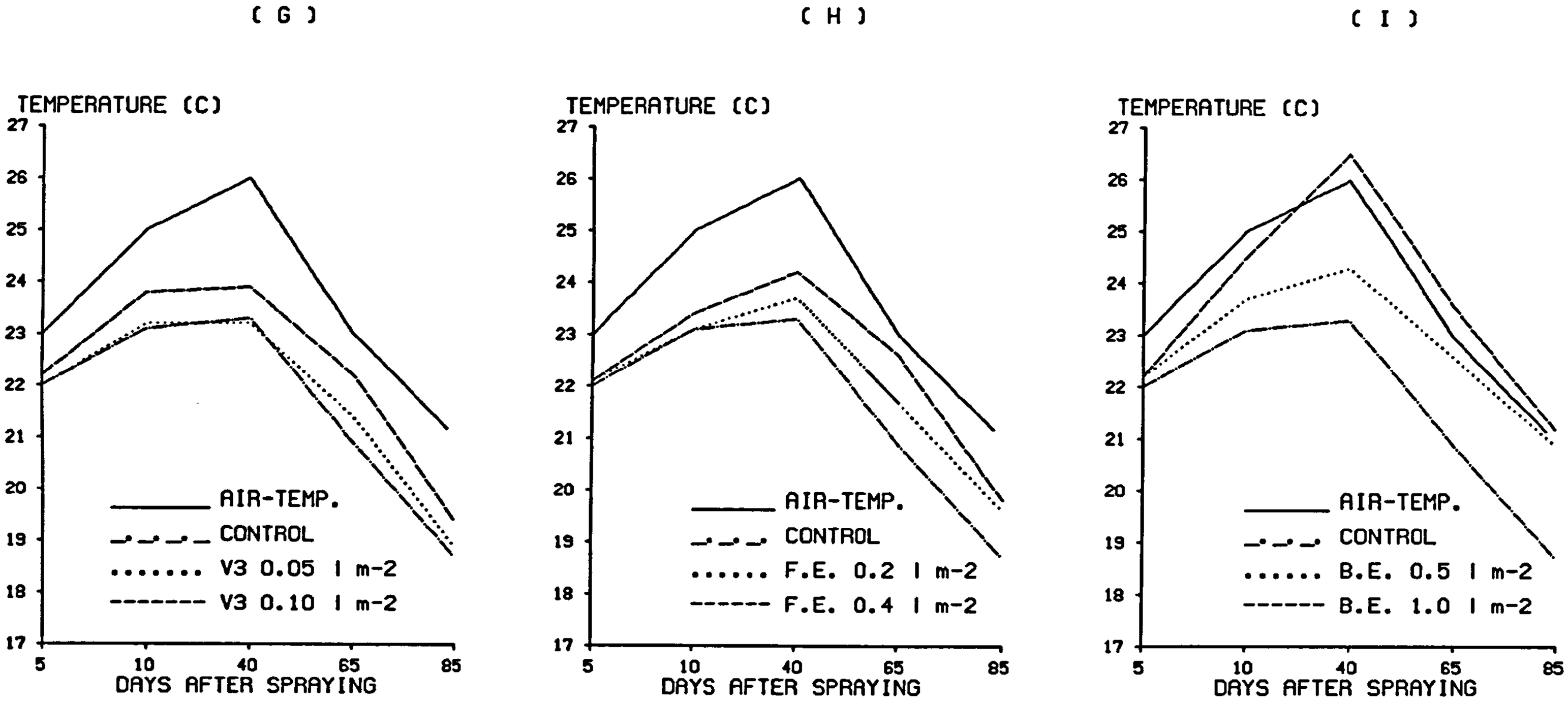


FIG. 5.38 (G - I): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE SURFACE TEMPERATURE OF DRURIDGE BAY SAND (MARRAM GRASS EXPERIMENT).

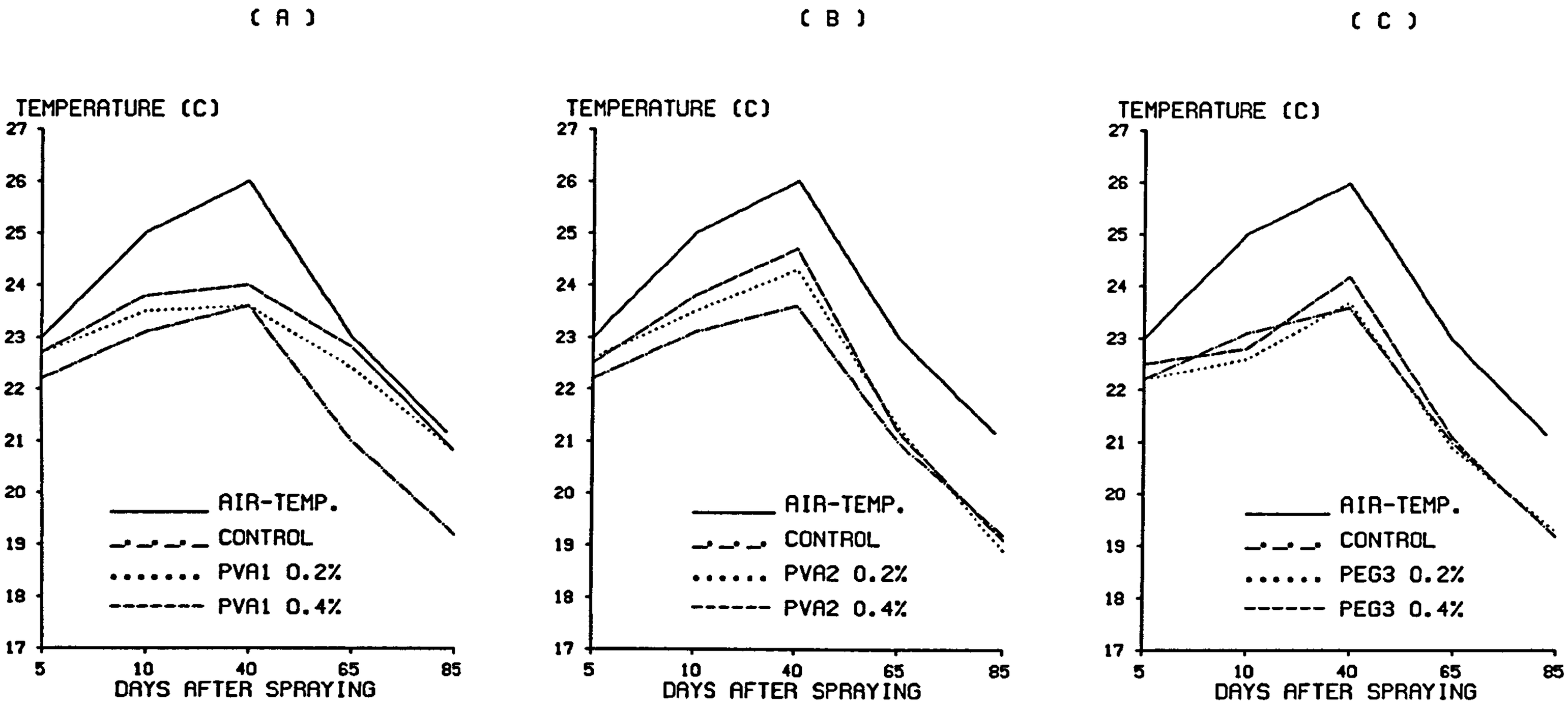
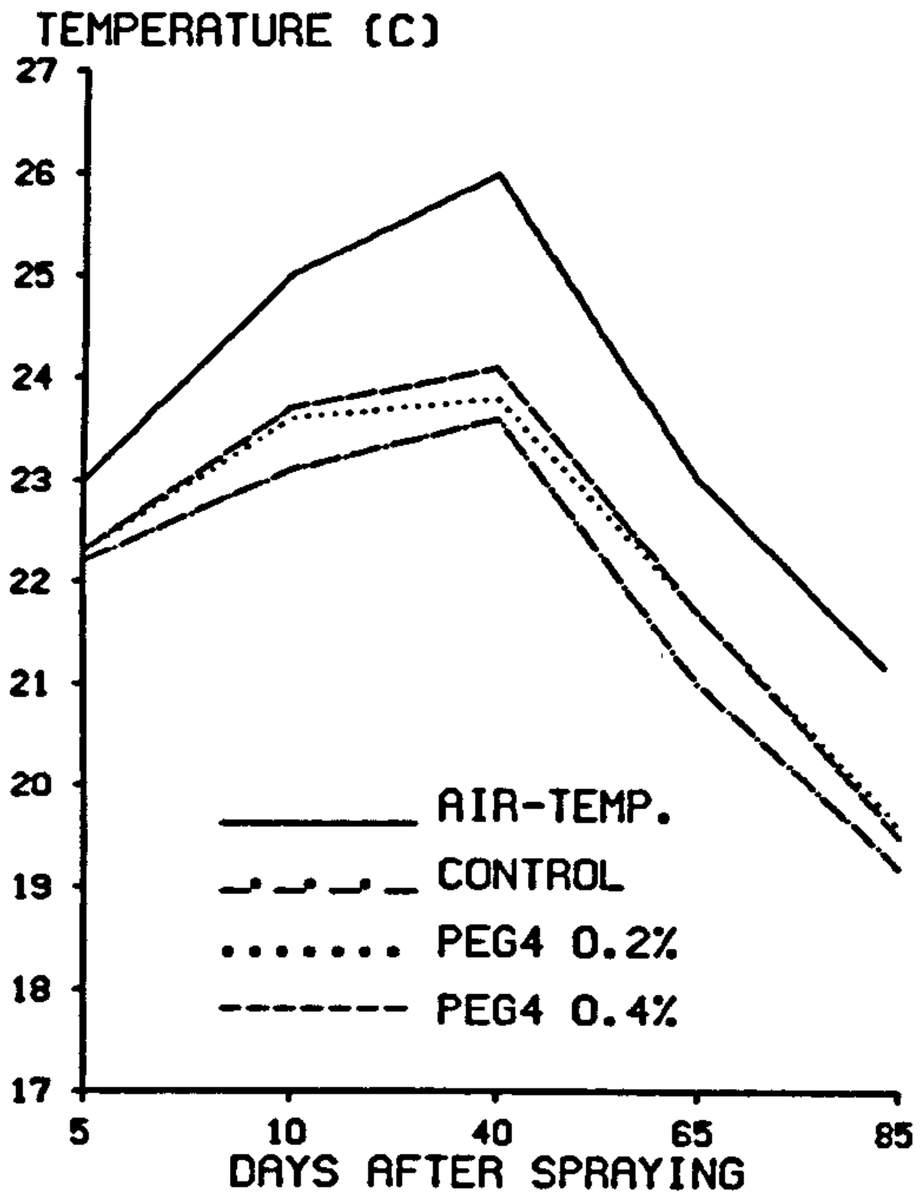
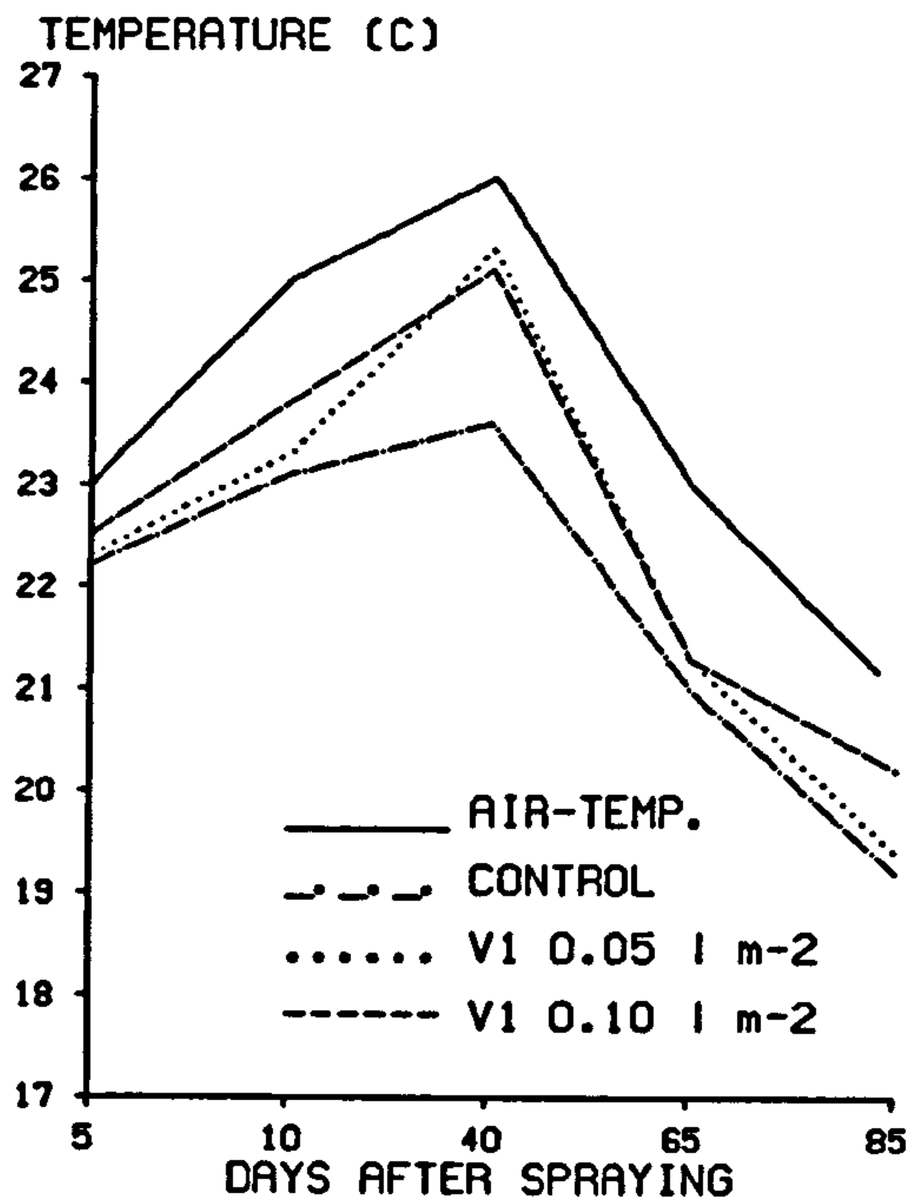


FIG. 5.39 (A - C): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE (5 cm DEPTH) TEMPERATURE OF DRURIDGE BAY SAND (MARRAM GRASS EXPERIMENT).

(D)



(E)



(F)

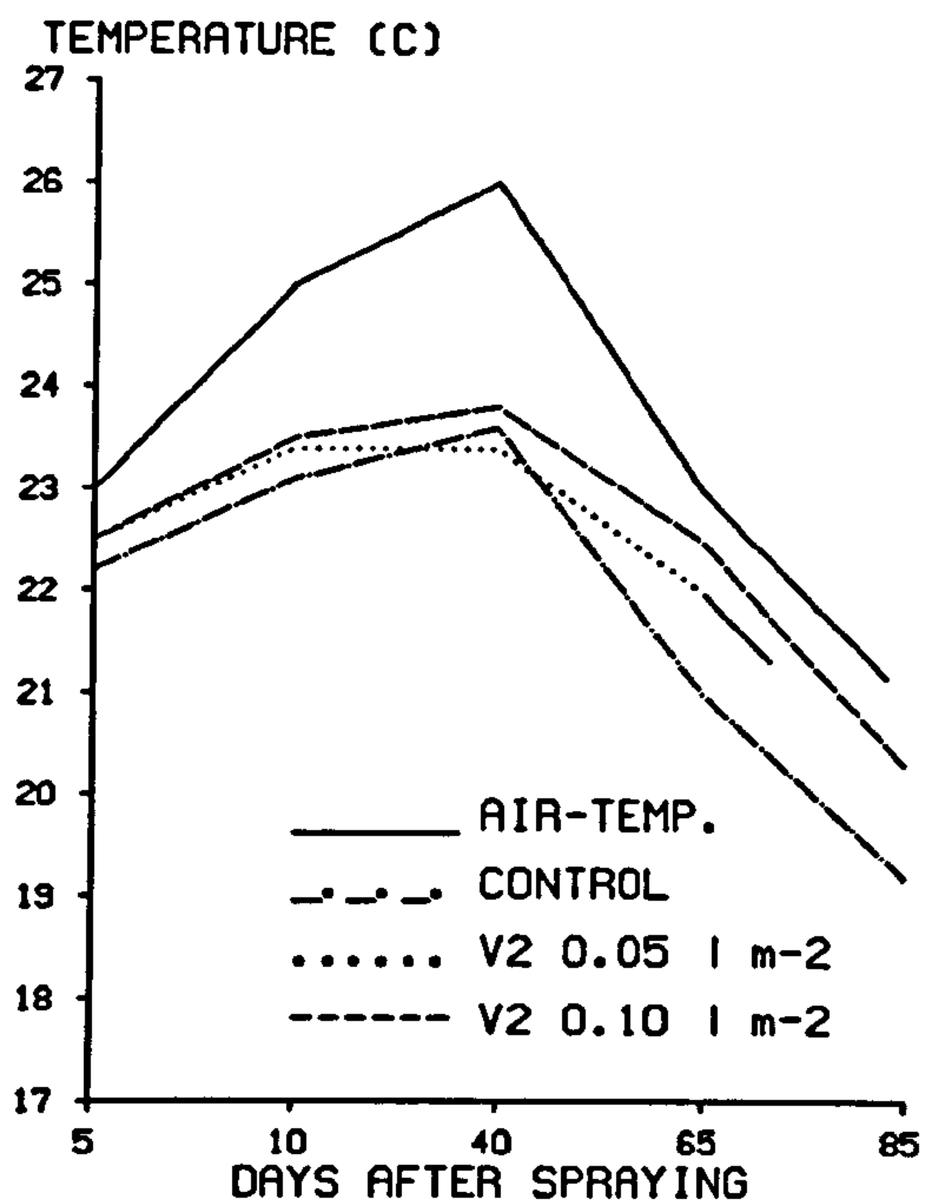


FIG. 5.39 (D - F): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE (5 cm DEPTH) TEMPERATURE OF DRURIDGE BAY SAND (MARRAM GRASS EXPERIMENT).

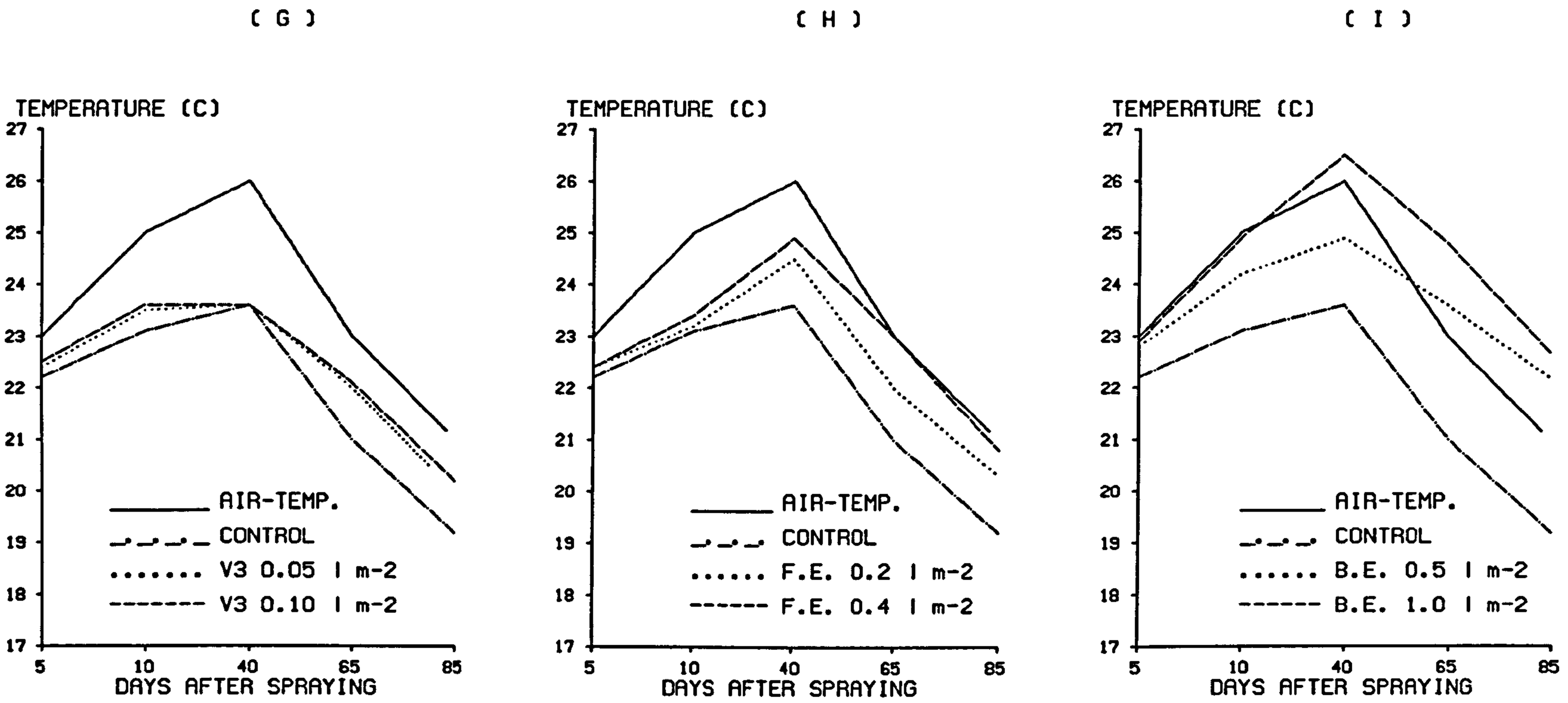


FIG. 5.39 (G - I): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE (5 cm DEPTH) TEMPERATURE OF DRURIDGE BAY SAND (MARRAM GRASS EXPERIMENT).

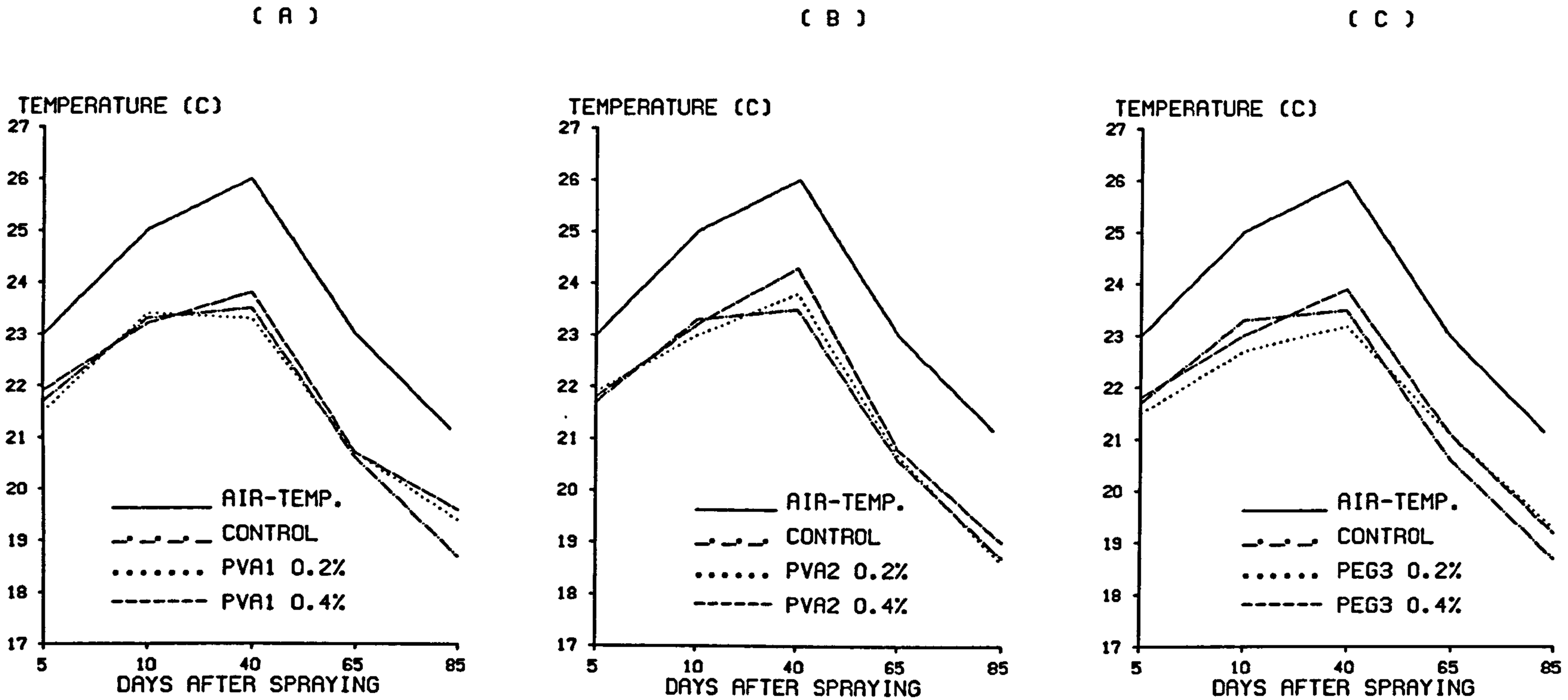


FIG. 5.40 (A - C): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE (10 cm DEPTH) TEMPERATURE OF DRURIDGE BAY SAND (MARRAM GRASS EXPERIMENT).

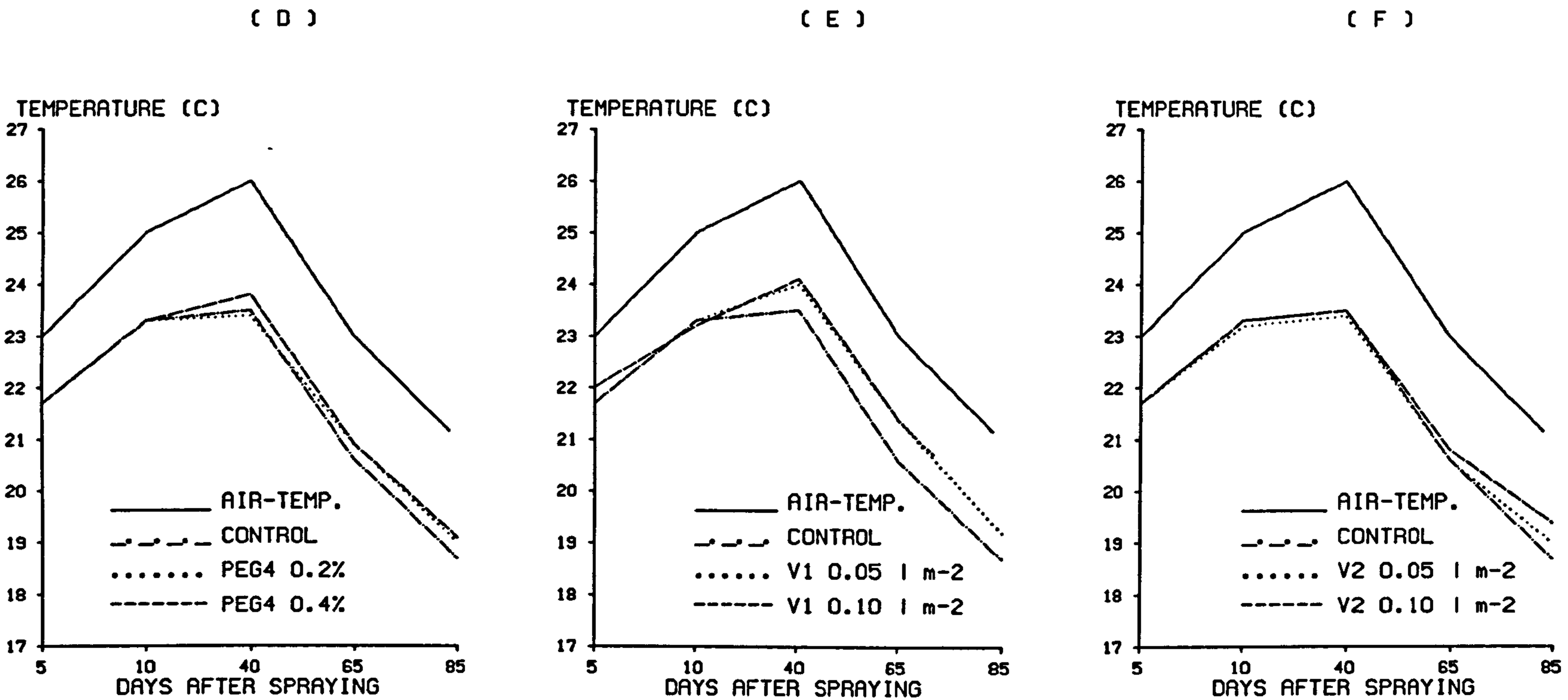


FIG. 5.40 (D - F): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE (10 cm DEPTH) TEMPERATURE OF DRURIDGE BAY SAND (MARRAM GRASS EXPERIMENT).

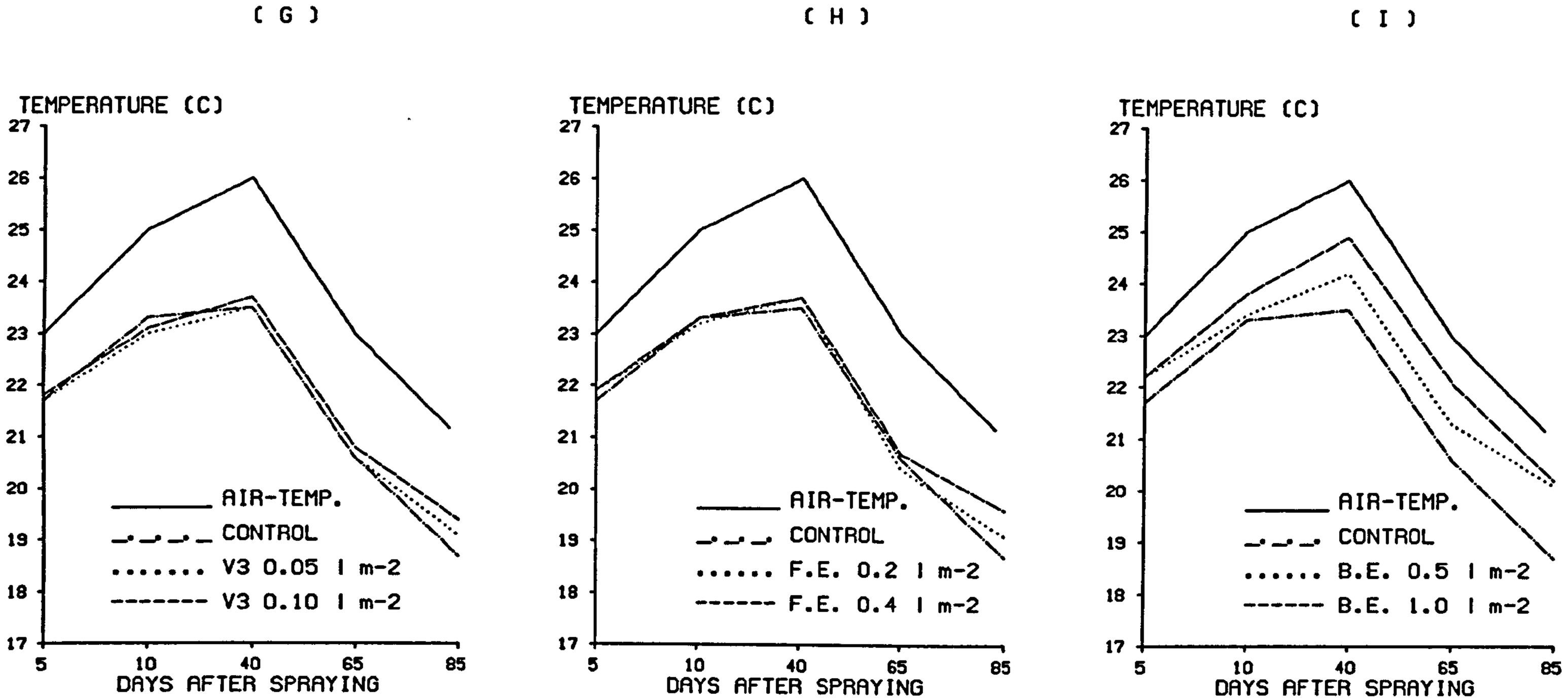


FIG. 5.40 (G - I): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE (10 cm DEPTH) TEMPERATURE OF DRURIDGE BAY SAND (MARRAM GRASS EXPERIMENT).

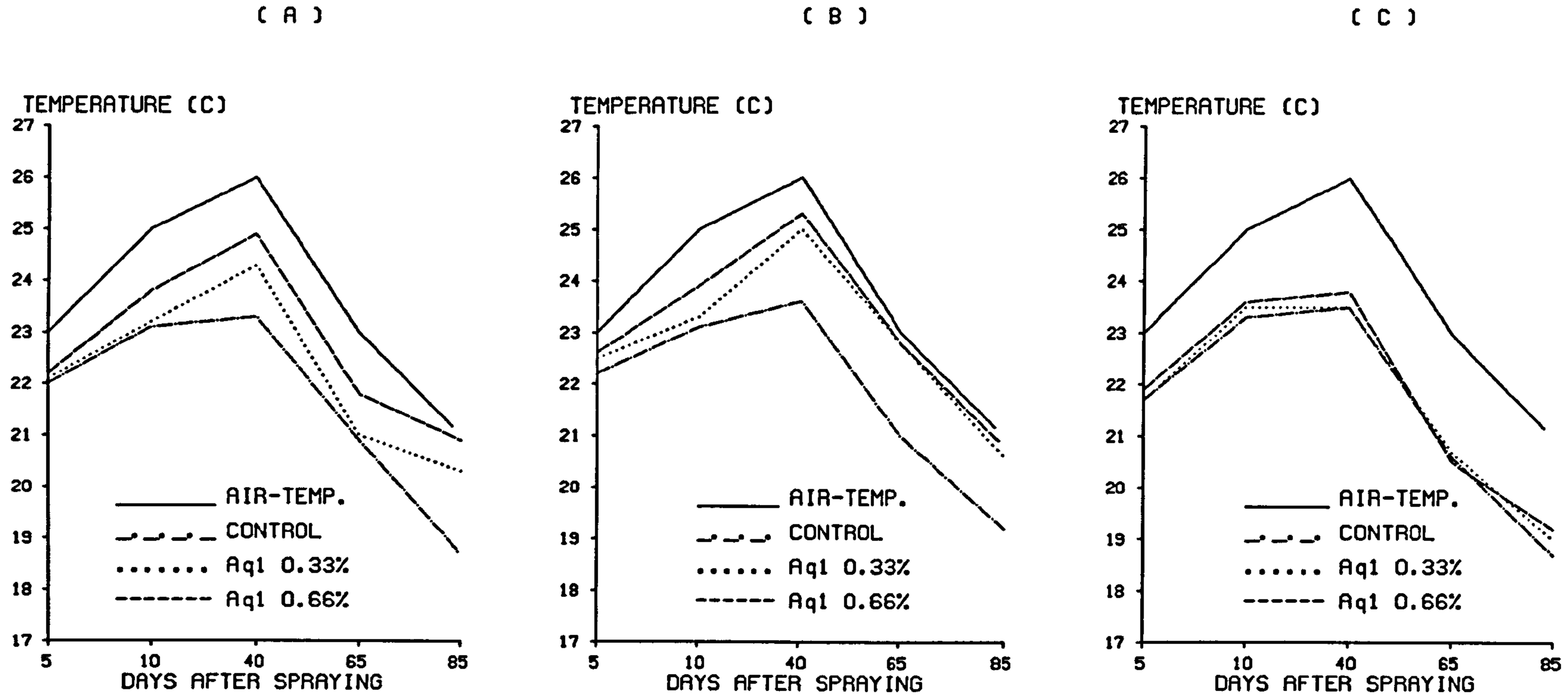


FIG. 5.41: EFFECT OF AQUAPOL 35-0019 ON THE SAND TEMPERATURE FROM DRURIDGE BAY AT THE DEPTHS: (A) SAND SURFACE; (B) 5 cm DEPTH; (C) 10 cm DEPTH (MARRAM GRASS EXPERIMENT).

Table 5.26: Effect of Various Chemical Stabilizers on the Surafce Temperature of Druridge Bay Sand (Eucalyptus Experiment).

Treats	Conc.*	Sand Surface Temperature After Days From Spraying					
		5	10	40	65	85	Mean
PVA1	0.2%	22.8	24.9	27.4	24.8	20.5	24.1
	0.4%	22.7	24.8	27.3	24.7	20.9	24.1
PVA2	0.2%	22.9	24.4	26.5	23.8	20.6	23.6
	0.4%	23.0	24.7	26.4	23.7	20.2	23.6
PEG3	0.2%	22.9	24.7	26.8	23.7	20.0	23.6
	0.4%	22.7	24.5	27.1	23.8	20.5	23.7
PEG4	0.2%	22.7	24.3	27.3	23.9	20.0	23.6
	0.4%	22.5	24.3	27.8	23.9	19.8	23.7
V1	0.05 l m^{-2}	22.5	24.2	28.6	24.9	20.3	24.1
	0.10 l m^{-2}	22.8	24.2	28.9	25.0	20.1	24.2
V2	0.05 l m^{-2}	22.8	24.3	28.2	25.1	20.5	24.2
	0.10 l m^{-2}	22.9	24.5	28.5	25.0	20.4	24.3
V3	0.05 l m^{-2}	23.0	24.5	28.0	24.6	20.5	24.1
	0.10 l m^{-2}	23.1	24.3	28.1	25.3	20.8	24.3
F.E.	0.2 l m^{-2}	23.0	24.3	32.7	24.6	20.4	25.0
	0.4 l m^{-2}	22.9	24.3	35.1	24.8	20.8	25.6
B.E.	0.5 l m^{-2}	22.9	24.4	34.2	25.3	21.1	25.6
	1.0 l m^{-2}	22.9	24.6	35.3	27.8	20.9	26.3
Aq1	0.33%	23.2	24.3	30.7	25.3	20.3	24.8
	0.66%	23.8	24.6	32.5	26.8	21.1	25.8
Control		22.1	24.2	27.0	24.3	20.2	23.6
Air-temperature		23∓1	25∓1	32∓1	27∓1	21∓1	25.6∓1

* All (%) are on the base of air-dry sand.

Table 5.27: Effect of Various Chemical Stabilizers on the (5 cm Depth) Temperature of Druridge Bay Sand (Eucalyptus Experiment).

Treats	Conc.*	Sand Temperature After Days From Spraying					
		5	10	40	65	85	Mean
PVA1	0.2%	22.6	24.2	25.4	24.3	20.0	23.3
	0.4%	22.8	24.1	25.6	24.6	20.2	23.5
PVA2	0.2%	22.5	23.5	25.3	24.1	22.0	23.5
	0.4%	22.7	23.6	25.4	24.0	21.9	23.5
PEG3	0.2%	22.9	22.9	25.0	24.3	21.1	23.2
	0.4%	23.3	23.7	25.8	24.8	21.2	23.8
PEG4	0.2%	22.5	24.0	24.9	23.7	20.1	23.0
	0.4%	22.3	23.9	25.2	23.8	19.9	23.0
V1	0.05 l m^{-2}	22.7	23.8	26.0	25.1	20.5	23.6
	0.10 l m^{-2}	22.6	23.7	26.2	25.4	20.4	23.7
V2	0.05 l m^{-2}	22.8	23.8	25.3	24.5	20.3	23.3
	0.10 l m^{-2}	22.8	23.7	25.9	24.6	20.0	23.4
V3	0.05 l m^{-2}	23.0	23.9	24.8	24.3	20.4	23.3
	0.10 l m^{-2}	22.9	24.0	25.3	25.0	20.6	23.6
F.E.	0.2 l m^{-2}	22.6	22.8	26.9	24.8	20.4	23.3
	0.4 l m^{-2}	22.5	22.9	27.4	24.7	20.6	23.6
B.E.	0.5 l m^{-2}	22.8	23.9	27.8	25.3	20.8	24.1
	1.0 l m^{-2}	23.0	24.3	28.9	26.7	20.8	24.7
Aq1	0.33%	22.8	22.6	25.5	24.9	20.3	23.2
	0.66%	22.9	23.5	26.5	25.6	20.4	23.8
Control		22.0	22.3	24.9	24.3	20.1	22.7
Air-temperature		23∓1	25∓1	32∓1	27∓1	21∓1	25.6∓1

* All (%) are on the base of air-dry sand.

Table 5.28: Effect of Various Chemical Stabilizers on the (10 cm Depth) Temperature of Druridge Bay Sand (Eucalyptus Experiment).

Treats	Conc.*	Sand Temperature After Days From Spraying					
		5	10	40	65	85	Mean
PVA1	0.2%	22.6	22.8	23.9	22.9	20.0	22.4
	0.4%	22.8	22.9	23.7	22.8	20.2	22.5
PVA2	0.2%	22.5	22.7	24.3	23.3	20.8	22.7
	0.4%	22.6	22.8	24.3	23.4	20.6	22.7
PEG3	0.2%	22.1	22.7	23.8	23.3	20.0	22.4
	0.4%	22.7	23.1	24.1	24.0	20.2	22.8
PEG4	0.2%	22.4	22.8	24.1	23.3	20.4	22.6
	0.4%	22.5	22.6	24.7	23.3	20.5	22.7
V1	0.05 l m^{-2}	22.4	23.2	24.1	23.3	20.1	22.6
	0.10 l m^{-2}	22.5	23.0	24.2	23.3	20.3	22.7
V2	0.05 l m^{-2}	22.6	22.6	23.7	22.9	19.9	22.3
	0.10 l m^{-2}	22.8	22.6	23.8	23.2	20.1	22.5
V3	0.05 l m^{-2}	22.6	23.0	24.4	23.6	20.1	22.7
	0.10 l m^{-2}	22.4	23.1	24.1	23.6	20.1	22.7
F.E.	0.2 l m^{-2}	22.6	22.9	24.3	23.4	20.6	22.8
	0.4 l m^{-2}	22.5	22.9	24.5	23.2	20.8	22.8
B.E.	0.5 l m^{-2}	22.5	22.7	24.4	23.6	20.4	22.7
	1.0 l m^{-2}	22.6	22.6	24.5	23.5	20.6	22.8
Aq1	0.33%	22.4	22.7	23.9	23.3	20.3	22.5
	0.66%	22.4	22.8	24.1	23.0	20.5	22.6
Control		22.4	22.5	24.1	23.2	20.3	22.5
Air-temperature		23∓1	25∓1	32∓1	27∓1	21∓1	25.6∓1

* All (%) are on the base of air-dry sand.

Table 5.29: Effect of Various Chemical Stabilizers on the Surface temperature of Druridge Bay Sand (Marram Grass Experiment).

Treats	Conc.*	Sand Surface Temperature After Days From Spraying					
		5	10	40	65	85	Mean
PVA1	0.2%	22.7	23.2	23.3	21.8	18.7	21.9
	0.4%	22.7	23.4	23.7	21.9	19.3	22.2
PVA2	0.2%	22.1	23.4	23.7	20.9	18.6	21.7
	0.4%	22.6	23.7	24.4	21.3	18.7	22.1
PEG3	0.2%	21.7	22.8	23.2	20.8	18.8	21.5
	0.4%	22.3	22.9	23.4	20.9	18.8	21.7
PEG4	0.2%	21.9	23.0	22.9	20.9	18.8	21.5
	0.4%	21.9	23.2	23.4	21.1	18.9	21.7
V1	0.05 l m^{-2}	22.1	23.4	22.9	21.0	18.5	21.6
	0.10 l m^{-2}	22.2	23.6	23.8	21.0	18.8	21.9
V2	0.05 l m^{-2}	22.1	22.8	22.9	21.2	18.3	21.5
	0.10 l m^{-2}	22.3	22.9	23.0	21.4	18.9	21.7
V3	0.05 l m^{-2}	22.0	23.2	23.2	21.4	18.9	21.7
	0.10 l m^{-2}	22.2	23.8	23.9	22.2	19.4	22.3
F.E.	0.2 l m^{-2}	22.1	23.1	23.7	21.7	19.6	22.0
	0.4 l m^{-2}	22.1	23.4	24.2	22.6	19.8	22.4
B.E.	0.5 l m^{-2}	22.2	23.7	24.3	22.6	20.9	22.7
	1.0 l m^{-2}	22.2	24.5	26.5	23.6	21.2	23.6
Aq1	0.33%	22.1	23.2	24.3	21.0	20.3	22.2
	0.66%	22.2	23.8	24.9	21.8	20.9	22.7
Control		22.0	23.1	23.3	20.9	18.7	21.6
Air-temperature		23∓1	25∓1	26∓1	23∓1	21∓1	23.6∓1

* All (%) are on the base of air-dry sand.

Table 5.30: Effect of Various Chemical Stabilizers on the (5 cm Depth) Temperature of Druridge Bay Sand (Marram Grass Experiment).

Treats	Conc.*	Sand Temperature After Days From Spraying					
		5	10	40	65	85	Mean
PVA1	0.2%	22.7	23.5	23.6	22.4	20.8	22.4
	0.4%	22.7	23.8	24.0	22.8	20.8	22.8
PVA2	0.2%	22.6	23.5	24.3	21.3	18.9	22.1
	0.4%	22.5	23.8	24.7	21.2	19.1	22.3
PEG3	0.2%	22.2	22.6	23.7	20.9	19.3	21.7
	0.4%	22.5	22.8	24.2	21.1	19.1	21.9
PEG4	0.2%	22.3	23.6	23.8	21.7	19.6	22.2
	0.4%	22.3	23.7	24.1	21.7	19.5	22.3
V1	0.05 l m^{-2}	22.3	23.3	25.3	21.3	19.4	22.3
	0.10 l m^{-2}	22.5	23.8	25.1	21.3	20.2	22.6
V2	0.05 l m^{-2}	22.5	23.4	23.4	22.0	20.0	22.3
	0.10 l m^{-2}	22.5	23.5	23.8	22.5	20.3	22.5
V3	0.05 l m^{-2}	22.4	23.5	23.6	22.0	20.0	22.3
	0.10 l m^{-2}	22.5	23.6	23.6	22.1	20.2	22.4
F.E.	0.2 l m^{-2}	22.4	23.2	24.5	22.0	20.3	22.5
	0.4 l m^{-2}	22.4	23.4	24.9	23.0	20.8	22.9
B.E.	0.5 l m^{-2}	22.8	24.2	24.9	23.6	22.2	23.5
	1.0 l m^{-2}	22.9	24.9	26.5	24.8	22.7	24.4
Aq1	0.33%	22.5	23.3	25.0	22.8	20.6	22.8
	0.66%	22.6	23.9	25.3	22.8	20.8	23.1
Control		22.2	23.1	23.6	21.0	19.2	21.8
Air-temperature		23∓1	25∓1	26∓1	23∓1	21∓1	23.6∓1

* All (%) are on the base of air-dry sand.

Table 5.31 : Effect of Various Chemical Stabilizers on the (10 cm Depth) Temperature of Druridge Bay Sand (Marram Grass Experiment).

Treats	Conc.*	Sand Temperature After Days From Spraying					
		5	10	40	65	85	Mean
PVA1	0.2%	21.5	23.4	23.3	20.7	19.4	21.7
	0.4%	21.9	23.2	23.8	20.7	19.6	21.8
PVA2	0.2%	21.9	23.0	23.8	20.7	18.6	21.6
	0.4%	21.8	23.2	24.3	20.8	19.0	21.8
PEG3	0.2%	21.5	22.7	23.2	21.1	19.3	21.6
	0.4%	21.8	23.0	23.9	21.1	19.2	21.8
PEG4	0.2%	21.7	23.3	23.4	20.9	19.0	21.7
	0.4%	21.7	23.3	23.8	20.9	19.1	21.8
V1	0.05 l m^{-2}	21.7	23.3	24.0	21.4	19.2	21.9
	0.10 l m^{-2}	22.0	23.2	24.1	21.4	19.4	22.0
V2	0.05 l m^{-2}	21.7	23.2	23.4	20.6	19.0	21.6
	0.10 l m^{-2}	21.7	23.3	23.5	20.8	19.4	21.7
V3	0.05 l m^{-2}	21.7	23.0	23.5	20.6	19.1	21.6
	0.10 l m^{-2}	21.8	23.1	23.7	20.8	19.4	21.8
F.E.	0.2 l m^{-2}	21.9	23.2	23.7	20.4	19.1	21.7
	0.4 l m^{-2}	21.9	23.3	23.7	20.7	19.6	21.8
B.E.	0.5 l m^{-2}	22.2	23.4	24.2	21.3	20.1	22.2
	1.0 l m^{-2}	22.2	23.8	24.9	22.1	20.2	22.6
Aq1	0.33%	21.7	23.5	23.5	20.7	19.0	21.7
	0.66%	21.9	23.6	23.8	20.5	19.2	21.8
Control		21.7	23.3	23.5	20.6	18.7	21.6
Air-temperature		23∓1	25∓1	26∓1	23∓1	21∓1	23.6∓1

* All (%) are on the base of air-dry sand.

between the control and mulched samples was only 0.3°C. These chemicals were B.E. (1.0 l m^{-2}); F.E. (0.2 l $m^{-2}$and 0.4 l m^{-2}) and PEG3 (0.4%). Three samples had lower temperatures including: PVA1 (0.2%); PEG3 (0.2%) and V2 (0.05 l m^{-2}).

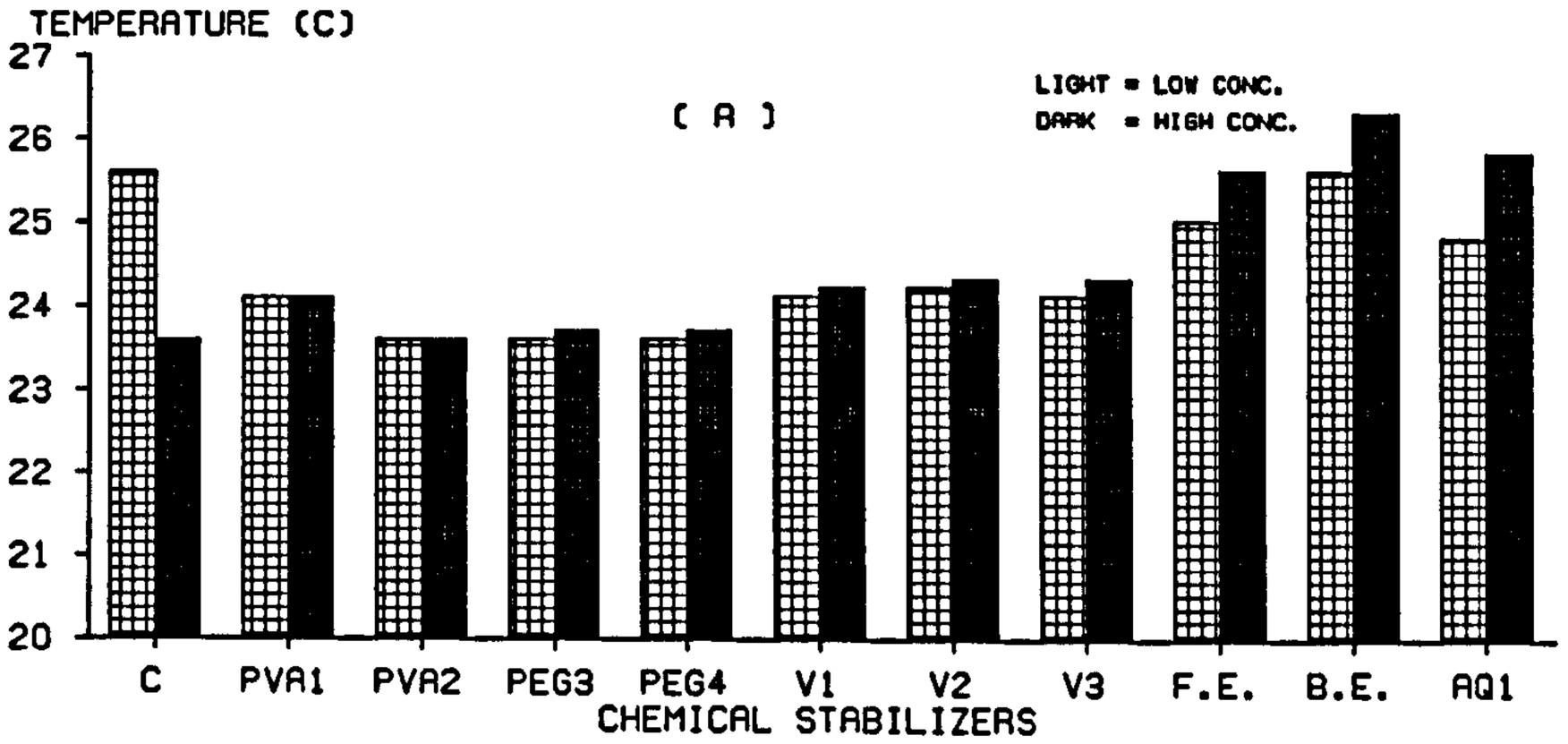
In the marram grass experiment, the F.E.; B.E. and Aq1 treatments again had the largest temperature differences from the control; although in this case the greatest increases were at 5 cm rather than at the surface. At 10 cm with the exception of the bitumen mulched sand all temperature differences were very similar.

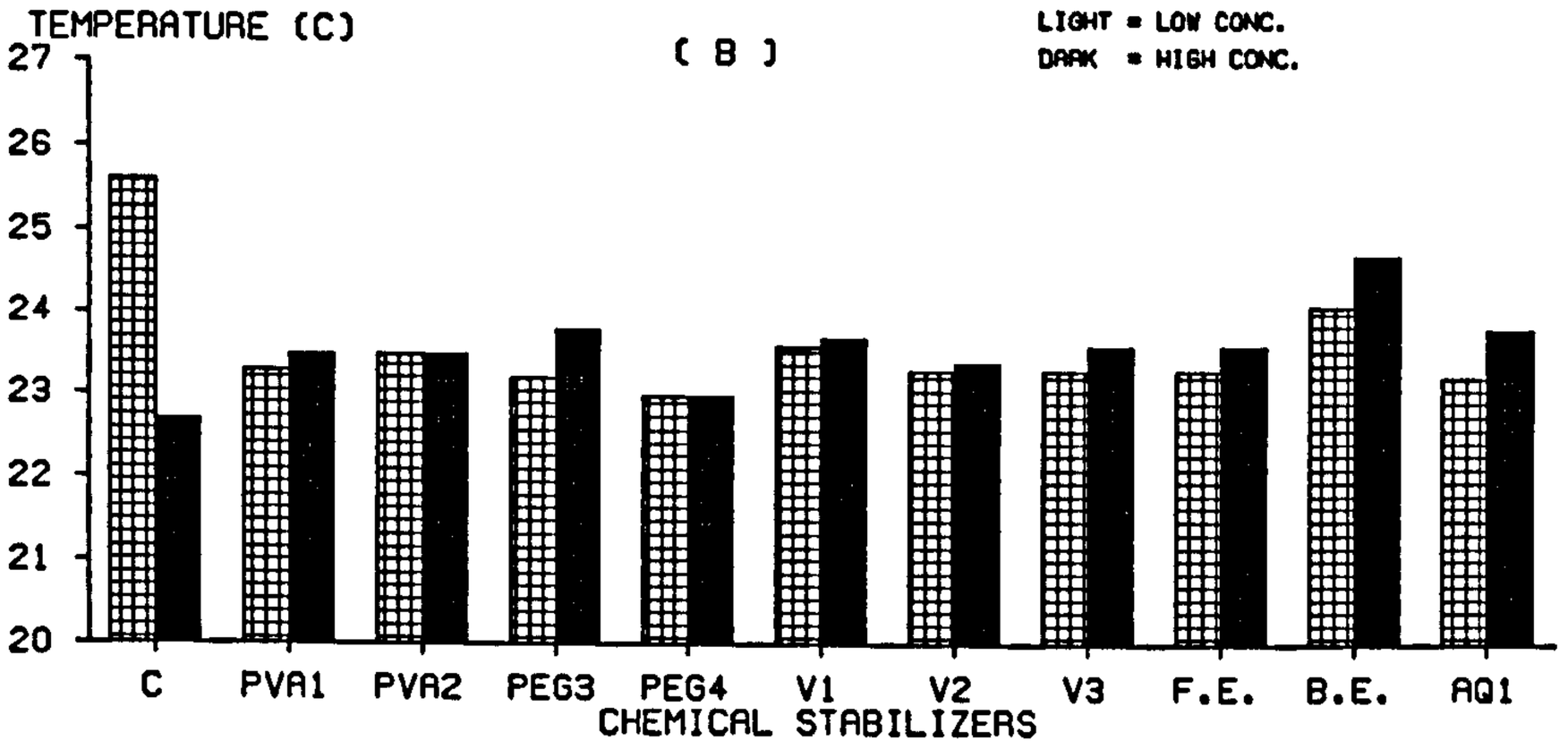
In most cases sand temperatures never exceeded the registered air-temperature. B.E. (1.0 l $m^{-2}$and 0.5 l m^{-2}); F.E. (0.4 l $m^{-2}$and 0.2 l m^{-2}) and Aq1 (0.66%) were the only mulches in which the temperature at the sand surface exceeded the recorded air-temperature in the *Eucalyptus spp.* experiment. This happened only when the air-temperature was very high (> 30°C). Under marram grass this only occurred with the bitumen emulsions.

Figures 5.42 and 5.43 illustrate the effect of two concentrations of each stabilizer on the mean temperatures of the sand samples at the sand surface; 5 cm and 10 cm depths for both *Eucalyptus spp.* and marram grass experiments. The low and high concentrations refer to the chemicals concentration given in table 4.2. In the control, the "light" blocks represent the air-temperatures, whilst the "dark" ones represent the untreated surface temperatures.

The results of the temperature experiments can be summarised as follows:-

1. Surface and 5 cm depth temperatures increase with both the application of the chemicals and also the concentration of the chemicals.
2. Sand temperatures in the *Eucalyptus spp.* experiment were always higher than those in the marram grass experiment. This was because of: (i) the recorded air-temperatures in the Eucalyptus experiment were higher than those during marram grass experiment, (ii) the differing growth form of the





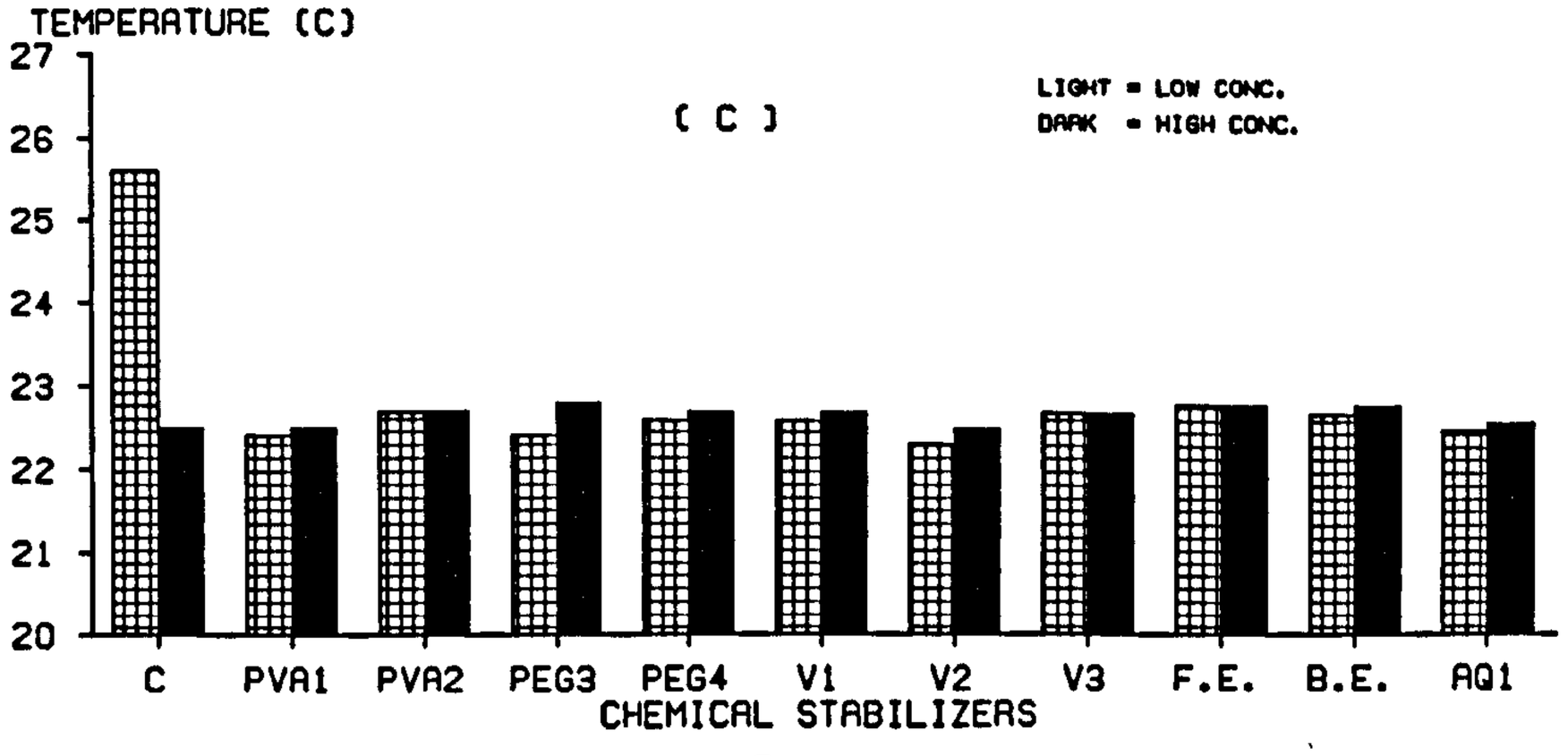


FIG. 5.42: EFFECT OF CHEMICAL STABILIZERS ON THE MEAN TEMPERATURE OF DRURIDGE SAND AT: (A) SAND SURFACE; (B) 5 cm DEPTH; (C) 10 cm DEPTH (EUCALYPTUS EXPERIMENT).

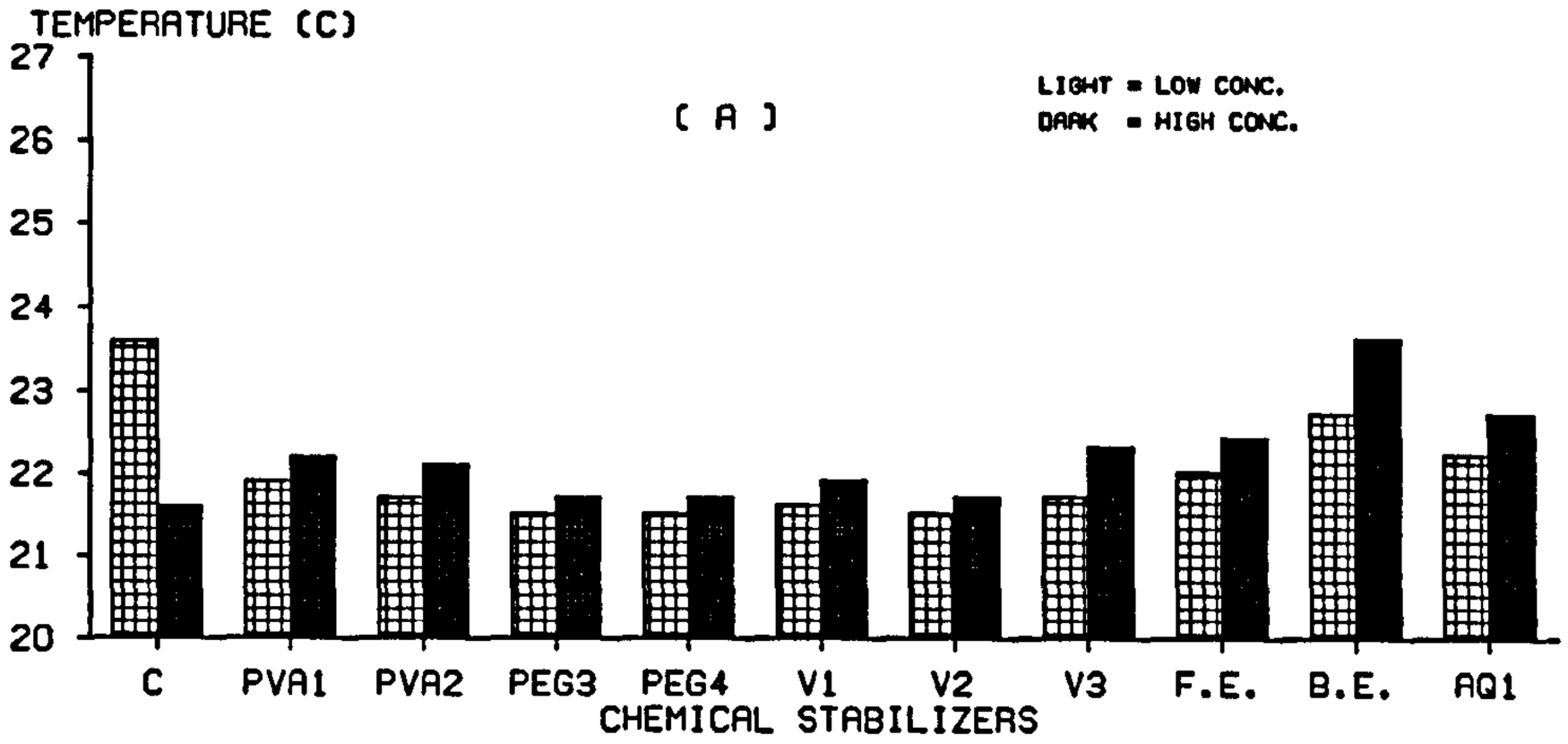


FIG. 5.43: EFFECT OF CHEMICAL STABILIZERS ON THE MEAN TEMPERATURE OF DRURIDGE SAND AT: (A) SAND SURFACE; (B) 5 cm DEPTH; (C) 10 cm DEPTH (MARRAM GRASS EXPERIMENT).

plants used. The single slim stem of the Eucalyptus provided little surface shade compared with the large number of marram grass tillers in each pot.

3. Surface temperatures under the effect of all treatments in the Eucalyptus experiment were higher than the temperatures at either 5 cm or 10 cm depths. Under marram grass however, the highest temperatures tended to be at the 5 cm depth. This anomaly is difficult to explain, it could be that the sand temperatures in the Eucalyptus experiment were measured in the 'heating-up' period, whilst those under marram grass were taken during the 'cooling-down' period.
4. The temperature differences decrease with depth, such that at 10 cm there is little differences between any of the treatments and the control.
5. It can be concluded from the results, that the chemical stabilizers B.E.; Aq1 and F.E. caused a greater increase in sand temperatures at the surface and at 5 cm than the remainder. Such an effect could be beneficial, in that it could both promote seed germination and increase the rate of growth of the seedling. However, in the summer season, especially in arid and semi-arid zones, when the soil surface is unshaded, this ability to raise soil temperature could adversely affect seeds germination especially of the temperatures exceeded 40 - 45°C (Callebaut and De Boodt, 1981).

5.1.4 Effect of Soil Chemical Stabilizers on Soil Water Evaporation

5.1.4.1 Theoretical Basis

The loss of water by evaporation is a serious problem for cultivation in arid and semi-arid regions, especially where irrigation water resources are limited (Tayel et al., 1981d). Olsen et al. (1964); Gerard and Champers (1967); Hillel and Berliner (1974) and many others have tried to cut down soil water evaporation by using soil conditioners.

Hydrophobic chemical materials reduce water evaporation because the capillary forces necessary to move water to the soil surface are reduced (DeBano, 1975). For example, a sand made water repellent by treatment with chaparral litter extract lost 45% of the water in contrast to an untreated wettable sand which lost 60% of its water during the same period (Letey et al., 1962b).

Synthetic organic chemicals, dimethyl octadecyl ammonium chloride (DDAC) was found to be effective in reducing water evaporation in three of the four treatments applied to a fine sandy loam soil (Bowers and Hanks, 1961). The lowest concentration (0.01% DDAC) increased evaporation slightly.

In an experiment using soil columns placed in the field, Kijne (1968) found that treating the soil surface by either spraying or mulching an acetyl alcohol solution could reduce the cumulative evaporation of the soil.

In both laboratory and pot experiments, alkylammonium chloride (RNH2.HCl) reduced evaporation from treated calcareous chernozem by a factor of two as compared to the control (Kerchev et al., 1976).

Szczypa et al. (1976) found that the total water capacity and water retention were greater in sandy soils treated with Gigtar-s soil conditioner (its active substance is partly hydrolized PAM) when compared to the original soils.

Coarse volcanic soils treated with bitumen emulsions reduced water evaporation by 40% (Lenvain and De Boodt, 1976). Gabriels et al. (1978) found that the

reduction in water evaporation was more effective in silt loam soil samples with a 2 cm top-layer treated with bitumen as compared with PVA. A 100 percent increase in moisture content and nitrogen retention was observed when an asphalt subsurface barrier 2 mm thick at a depth of 60 cm was used in a cultivated loamy sand soil (Gupta and Aggarwal, 1980).

Tayel and El-Hady (1981c) found that the drop in water loss via evaporation from a sandy soil treated with different concentrations of "Super gel" (0.05 - 0.20%) is increased with increasing the rate of application.

The reduction in the total water evaporation from a soil under the effect of synthetic surface mulches, could result, either from an increase in the rate of drying in the surface layer (Hedrick and Mowry, 1952), or by making the soil surface hydrophobic after the treatment (Kolasew, 1941; and Sukhovolshaia, 1941).

Hartmann et al. (1976) illustrated that a bare sandy loam soil rapidly lost water in the upper 30 cm. Soil treatments with PAM, and asphalt emulsion were effective in reducing the evaporation in the initial stage of the drying process but later lost their effectiveness. The reduction in water evaporation under the treated soils was probably due to the existence of a dry, well-aggregated surface zone that may act as a diffusion barrier reducing the water movement.

With abundant evidence to show that surface mulches can reduce evaporation from treated soils, a series of experiments were initiated to investigate the influence of the different soil stabilizers applied as a mulch on the amount of water held in Druridge Bay sand.

5.1.4.2 Techniques, Materials and Methods

Two evaporation trials were conducted in plastic pots of cross section (31.2 cm^2) containing 400 gm of air-dry Druridge Bay sand. These two trials were conducted as follows:-

Trial 1: Water Evaporation from Saturated Sand Samples:

In this experiment, plastic, closed bottom pots were uniformly packed with 400 gm of sand and the chemicals under test were applied to the sand surface at a rate equivalent to 6.0 l $m^{-2}$for each concentration, each trial was duplicated giving 42 pots in all. After leaving the samples for 24 hours to dry, an exact volume of distilled water (100 ml) was applied to the surface of each pot, 100 ml of water was enough to saturate the 400 gm sand sample. Care was taken during the application of the distilled water to allow any air inside the pots to escape. All samples were arranged in two lines. Heat was applied to the sand surface with a 30 watt strip bulb mounted 35 cm above the surface of the sand. Water losses due to evaporation were determined every 24 hours over a 6 day period.

Trial 2: Water Evaporation from the Sand Samples Through the Capillary Rise:

In this experiment, a second set of forty two pots was used, this time five holes were punched in the base of each pot, prior to the addition of 400 gm air-dry sand a layer of cotton wool was placed in the base of the pot to prevent loss of sand, and from each hole protruded a piece of cotton to act as a wick. Each pot was then placed inside a second pot to act as a reservoir to keep the sand moist during the course of the experiment. The same treatments were applied as in experiment 1. The pots were placed under a 30 watt strip bulb mounted 35 cm above the samples. Water loss and maximum and minimum air temperatures were recorded every 24 hours over 6 days.

5.1.4.3 Results and Discussions

1. Water Evaporation from Saturated Sand Samples:

The effect of various chemical stabilizers on the evaporation rate (cm^3 day^{-1}) from the sand samples is illustrated in figure (5.44), whilst their effect on the

cumulated evaporation percentages per pot during 6 days of tests is shown in table (5.32).

Chemicals PVA1; PVA2; V1; V2; V3; F.E.; B.E. and Aq1 reduced the rate of evaporation, and consequently the cumulated evaporation percent. The reduction was very high with both F.E. treatments and both B.E. treatments and high with the higher concentrations of PVA1; PVA2; V1 and Aq1. As reported by Tayel and El-Hady (1981c) and Tayel et al. (1981d), the rate of evaporation decreased as the concentration of the chemical used increased. The reduction in evaporation from the treated sand samples, could be caused either by the sand surface becoming hydrophobic after treatment (Kolasew, 1941; and Sukhovolshaia, 1941), or because of the formation of a chemical film which retards the escape of water and vapor to the atmosphere (Gabriels et al., 1975).

Not all the chemical materials reduced evaporation, PEG3; and PEG4 slightly increased both evaporation rate and the cumulated evaporation from the sand.

As expected, the maximum air-temperature (table 5.32) controlled both the evaporation rate and the cumulated evaporation from all samples. The reduction in the evaporation rate with all treatments on the 4th day compared with the 3rd day, even though the maximum air-temperature in both days was the same (24^{o}C), was due to the reduction in total water content within each pot.

Figure (5.45) indicates the effect of all chemical treatments on the total cumulated evaporation. Low and high concentrations are for the chemicals concentrations as in table (4.2 in chapter 4). It is clear that, with all chemicals, the cumulated evaporation decreases with the increase in chemical concentration; the reduction was very high with bitumen emulsions and PVA solutions, while it was very low with the F.E.; V2; V3 and PEG3. Thus the most effective chemicals are:- F.E. > B.E. > PVA1 > PVA2 > Aq1 > the rest of the chemical treatments and the control.

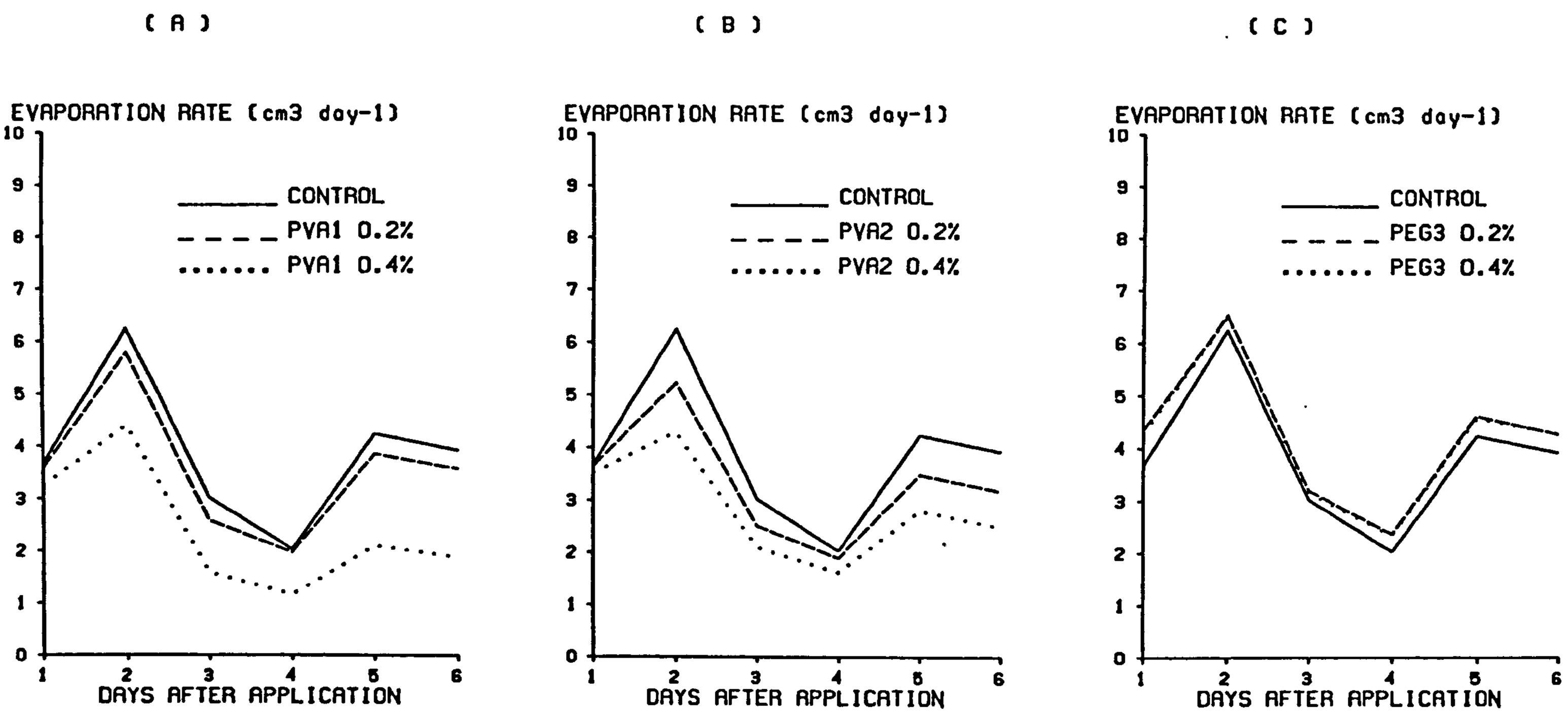
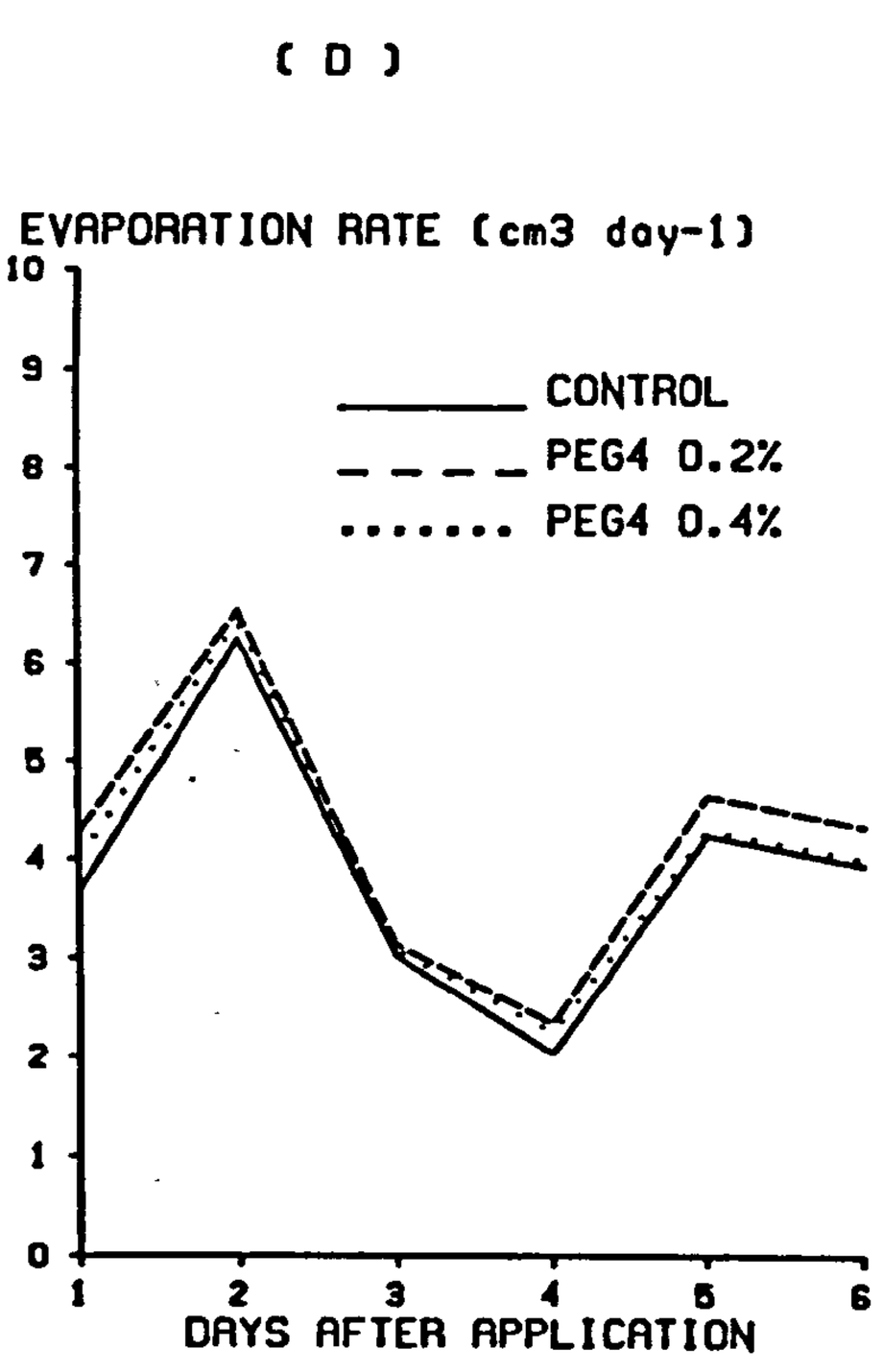
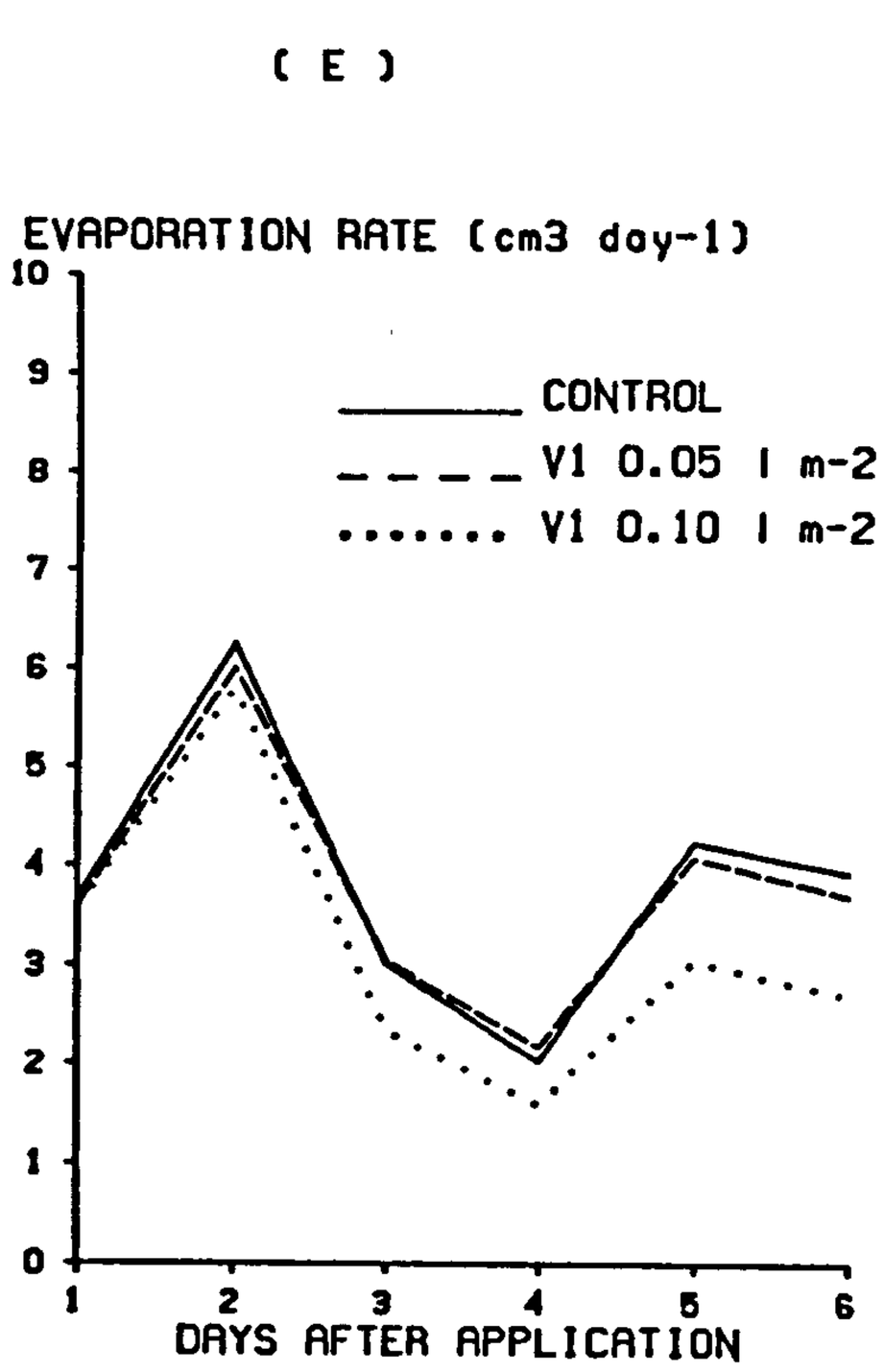


FIG. 5.44 (A - C): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE EVAPORATION RATE FROM DRURIDGE BAY SAND SAMPLES SATURATED WITH WATER.





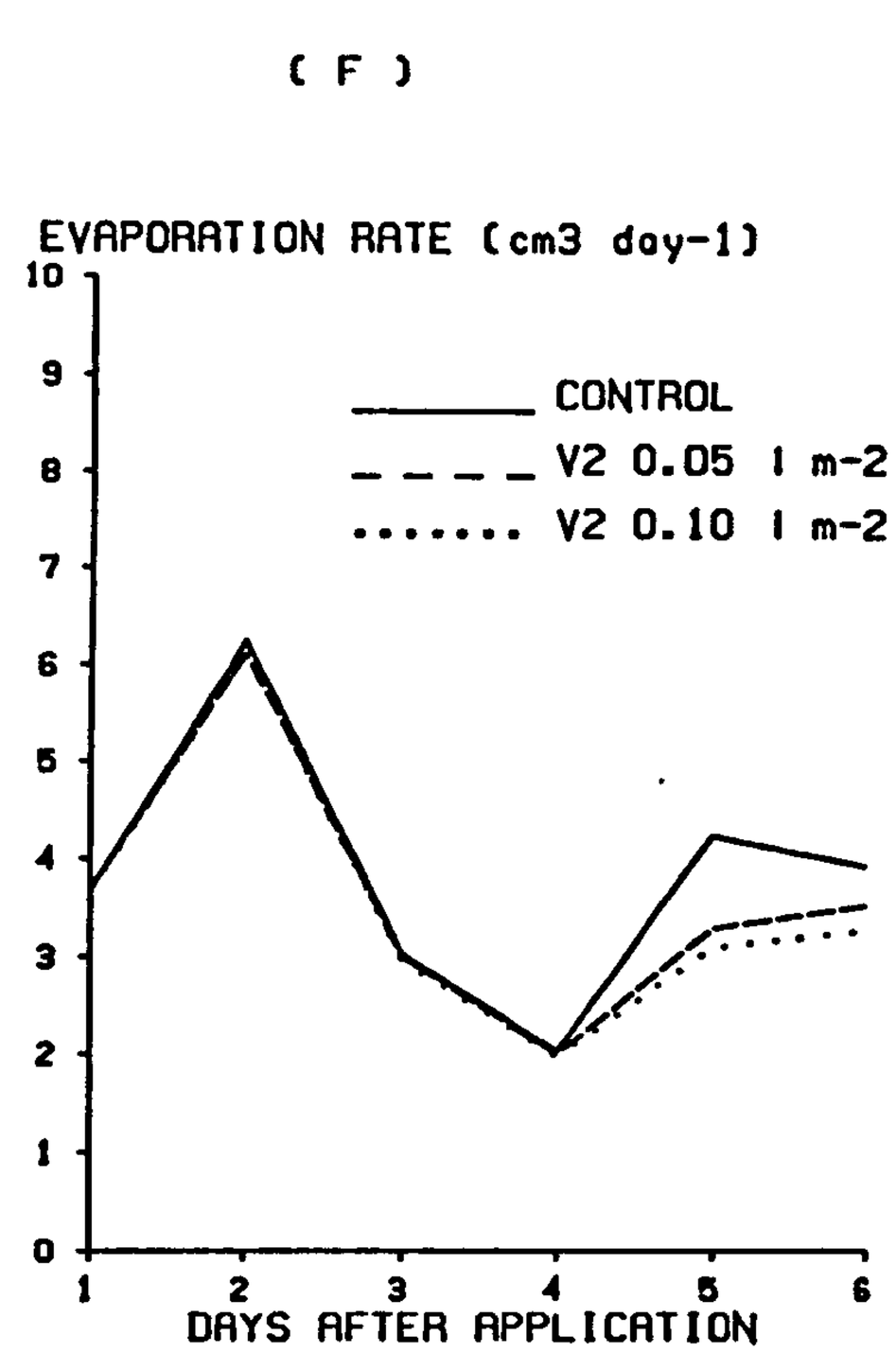


FIG. 5.44 (D - F): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE EVAPORATION RATE FROM DRURIDGE BAY SAND SAMPLES SATURATED WITH WATER.

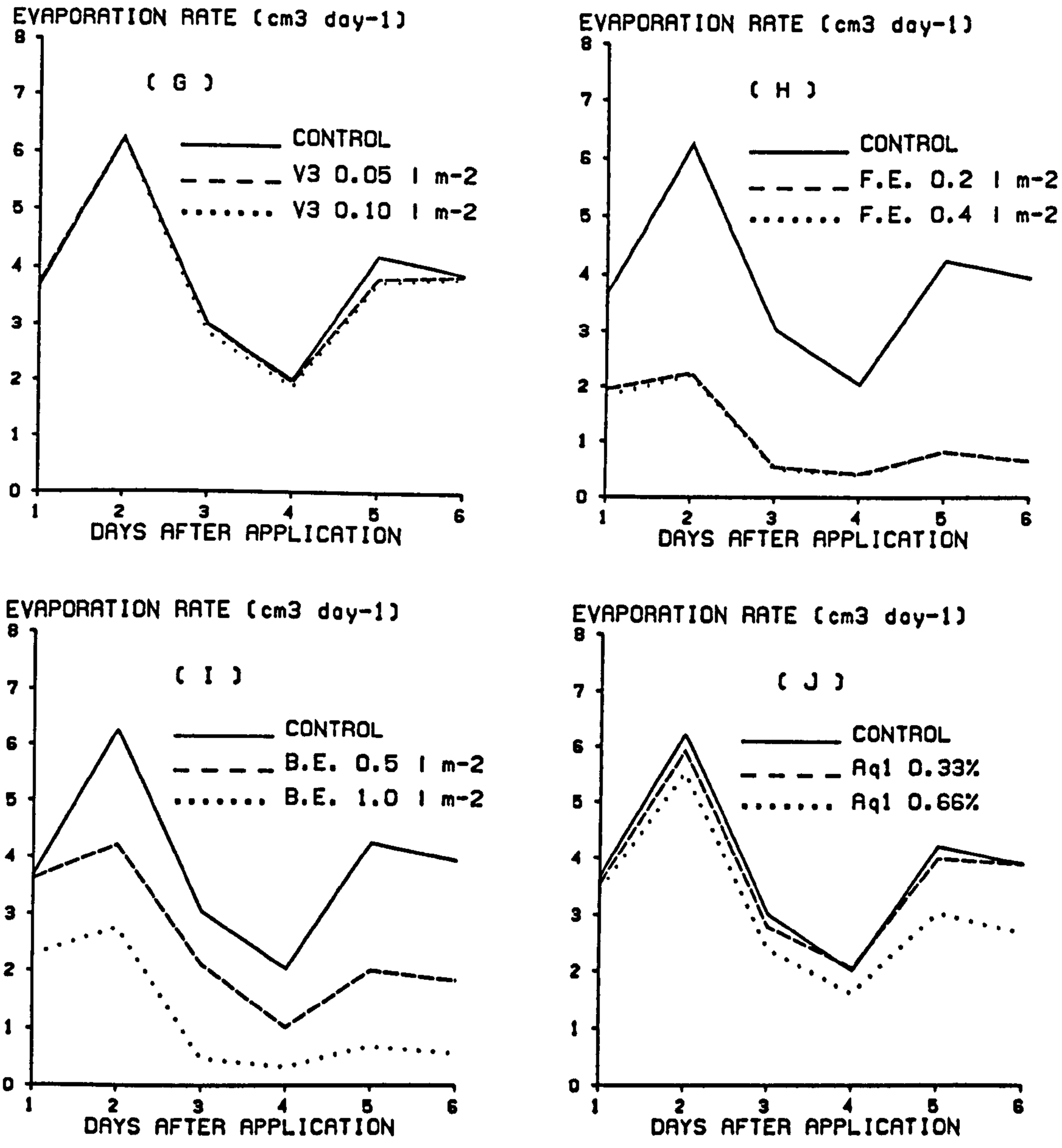


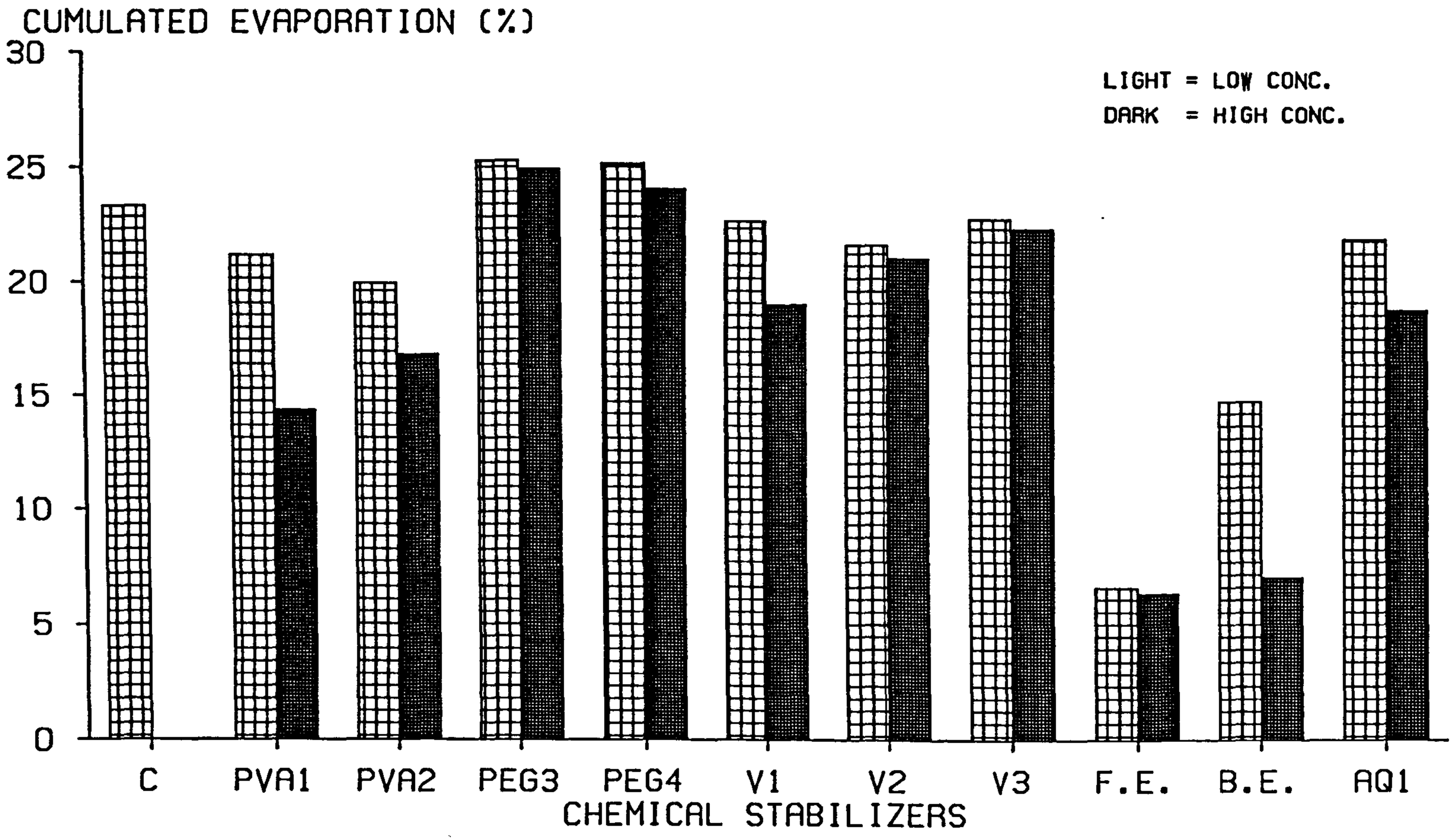
FIG. 5.44 (G - J): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE EVAPORATION RATE FROM DRURIDGE BAY SAND SAMPLES SATURATED WITH WATER

Table 5.32: Effect of Various Chemical Materials on Water Evaporation from Druridge Bay Sand Water Saturated Samples.

Treats	Conc.*	Cumulated Evaporation Percent Per Pot After Days					
		1	2	3	4	5	6
PVA1	0.2%	3.55	9.28	11.85	13.80	17.63	21.18
	0.4%	3.25	7.64	9.23	10.39	12.49	14.37
PVA2	0.2%	3.65	8.87	11.38	13.28	16.76	19.94
	0.4%	3.51	7.79	9.88	11.50	14.30	16.79
PEG3	0.2%	4.33	10.84	14.04	16.41	21.02	25.29
	0.4%	4.24	10.68	13.80	16.13	20.66	24.92
PEG4	0.2%	4.24	10.75	13.87	16.21	20.83	25.14
	0.4%	4.00	10.42	13.51	15.76	20.06	24.05
V1	0.05 l m^{-2}	3.59	9.59	12.65	14.83	18.92	22.62
	0.10 l m^{-2}	3.55	9.34	11.68	13.28	16.33	19.01
V2	0.05 l m^{-2}	3.69	9.79	12.79	14.79	18.08	21.60
	0.10 l m^{-2}	3.66	9.76	12.71	14.68	17.78	21.05
V3	0.05 l m^{-2}	3.73	9.98	12.99	14.98	18.83	22.73
	0.10 l m^{-2}	3.70	9.91	12.77	14.67	18.45	22.30
F.E.	0.2 l m^{-2}	1.95	4.20	4.75	5.17	5.98	6.63
	0.4 l m^{-2}	1.83	4.03	4.54	4.93	5.74	6.38
B.E.	0.5 l m^{-2}	3.62	7.82	9.92	10.94	12.94	14.77
	1.0 l m^{-2}	2.27	5.02	5.49	5.82	6.51	7.07
Aq1	0.33%	3.47	9.28	12.02	14.06	18.00	21.85
	0.66%	3.43	8.95	11.35	12.98	16.04	18.75
Control		3.65	9.86	12.88	14.90	19.12	23.32
Max. air-temp.		25.00	28.00	24.00	24.00	26.00	25.00
Min. air-temp.		17.50	20.00	19.00	19.00	19.00	18.00

* All (%) are on the base of air-dry sand.

FIG. 5.45: EFFECT OF VARIOUS CHEMICAL STABILIZERS ON CUMULATED EVAPORATION PERCENTAGES FROM DRURIDGE BAY SATURATED SAND SAMPLES AFTER SIX DAYS OF APPLICATION



2. Water Evaporation from the Sand Samples Through the Capillary Rise:

Figure (5.46) illustrates the evaporation rate from Druridge Bay sand samples through the capillary rise with the various chemical treatments, and table (5.33) shows the cumulated water evaporation through the capillary rise process.

The results show that the following stabilizers: PVA1; PVA2; V1; V2; V3; F.E.; B.E. and Aq1 reduced both evaporation rate and cumulated evaporation from the sand samples during the six days of the test. The remaining chemicals i.e. PEG3 and PEG4 increased both parameters when compared with the control.

As with the 1st evaporation experiment, the maximum air-temperature (table 5.33) controlled both evaporation rate and cumulated evaporation from all sand samples.

Figure (5.47) indicates the effect of all chemical treatments on the total cumulated evaporation (cm^3) through the capillary rise from the sand samples six days after application. Low and high concentrations are for the chemicals concentrations as in table (4.2). As in the case of water evaporation from the saturated sand samples experiment, as the chemical concentration increased so evaporation losses decrease. The order of effectiveness of the chemicals in this experiment are:- F.E. > B.E. > V2 > V3 > V1 > PVA1 > PVA2 > Aq1 > Control > PEG4 > PEG3.

In conclusion, the effect of PVA1; PVA2; PEG3; PEG4; V1; V2; V3; F.E.; B.E. and Aq1 chemicals treatments on water evaporation via capillary rise process or from saturated sand samples of Druridge Bay sand, can be summarized as follows:-

1. The rate of evaporation, cumulated evaporation, and consequently sand water retention varies with chemical type and the rate of application.
2. The decreases in both rate of water evaporation and cumulated evaporation, and therefore a corresponding increase in water retained in the treated sand samples were directly related to the concentration of the chemical used.

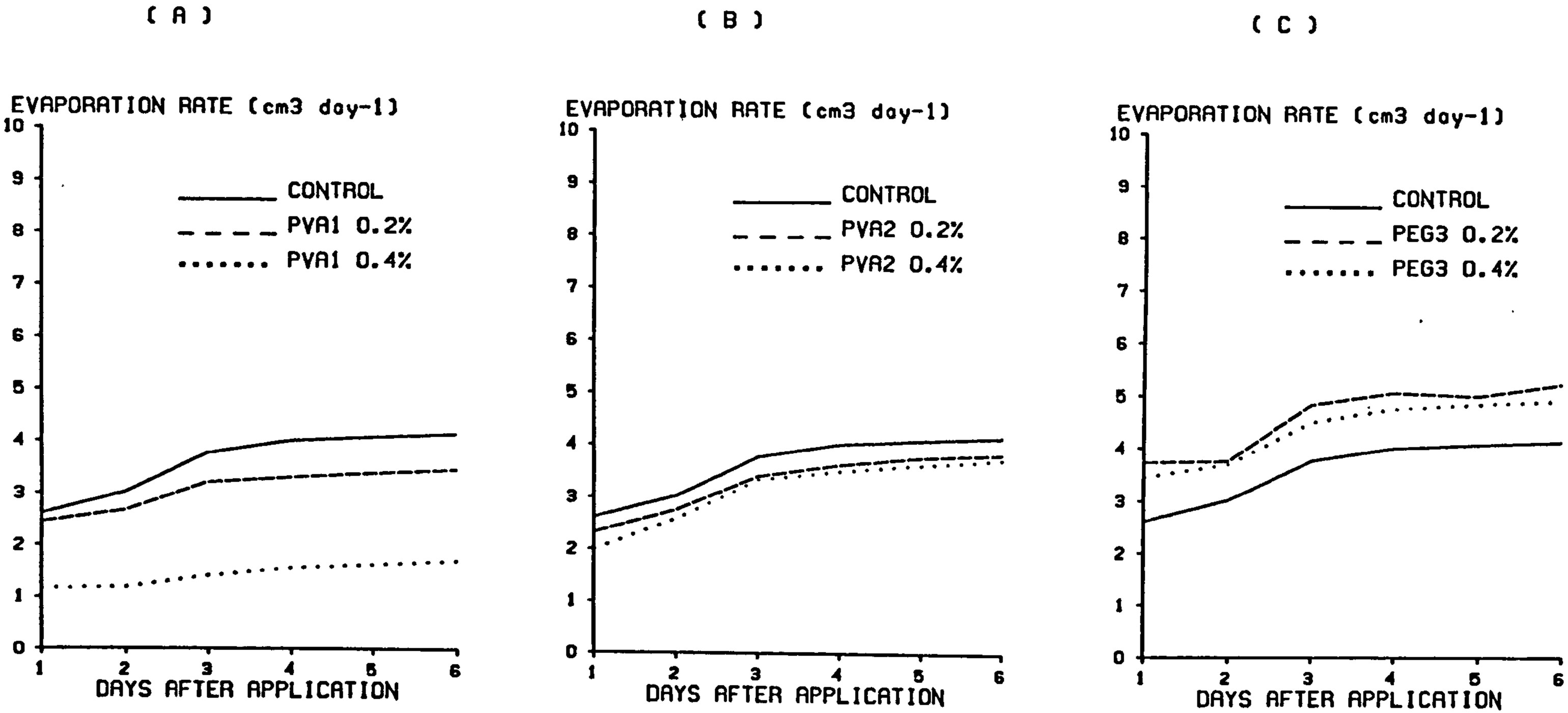


FIG. 5.46 (A - C): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE CAPILLARY RISE WATER EVAPORATION FROM DRURIDGE BAY SAND SAMPLES

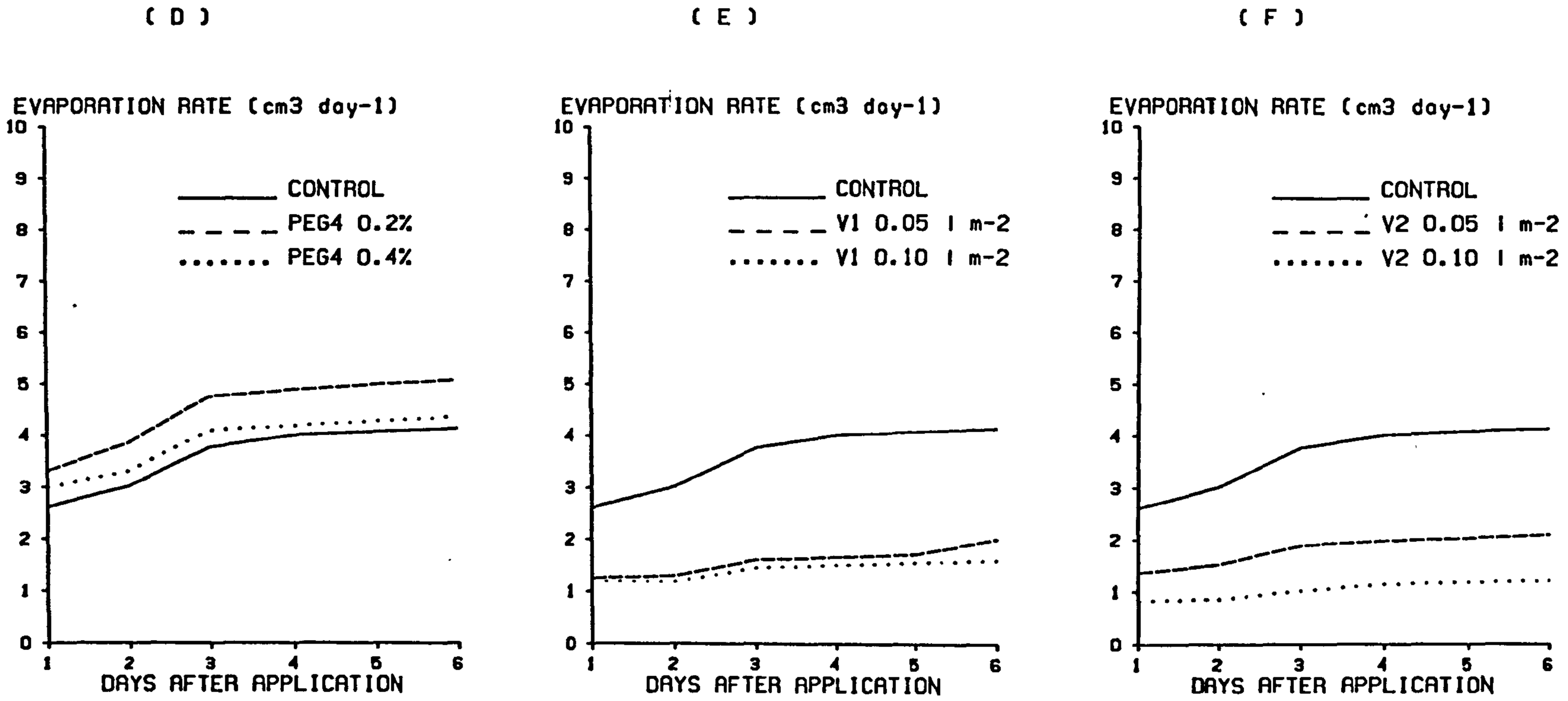


FIG. 5.46 (D - F): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE CAPILLARY RISE WATER EVAPORATION FROM DRURIDGE BAY SAND SAMPLES

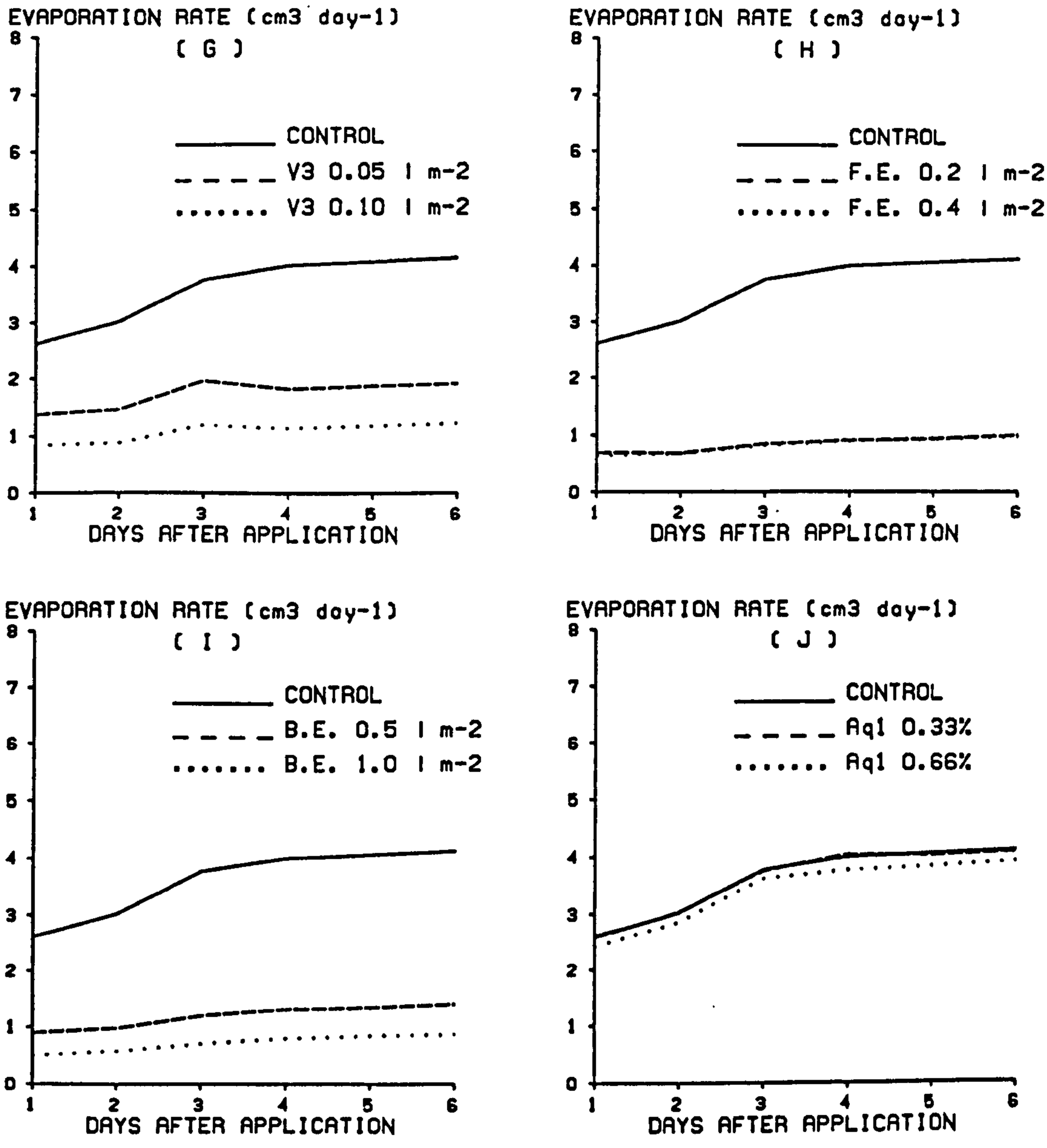


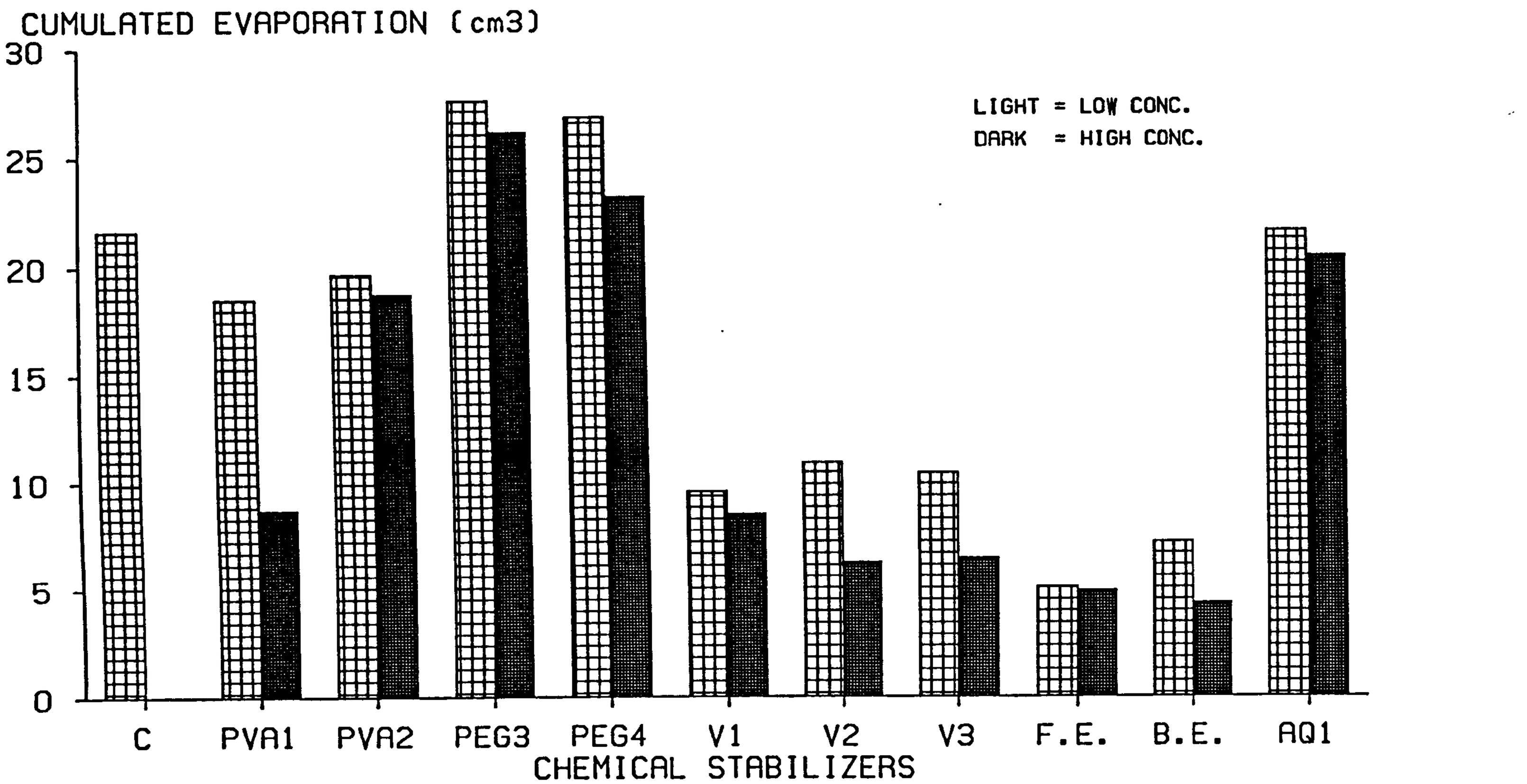
FIG. 5.46 (G - J): EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE CAPILLARY RISE WATER EVAPORATION FROM DRURIDGE BAY SAND SAMPLES

Table 5.33: Effect of Various Chemical Materials on the Capillary Rise Water Evaporation from Druridge Bay Sand Samples.

Treats	Conc.*	Cumulated Evaporation Per Pot After Days (cm^3)					
		1	2	3	4	5	6
PVA1	0.2%	2.45	5.12	8.33	11.64	15.03	18.49
	0.4%	1.16	2.35	3.76	5.32	6.95	8.66
PVA2	0.2%	2.32	5.07	8.47	12.09	15.85	19.67
	0.4%	1.99	4.57	7.90	11.40	15.02	18.74
PEG3	0.2%	3.73	7.49	12.33	17.40	22.41	27.65
	0.4%	3.45	7.15	11.65	16.41	21.27	26.20
PEG4	0.2%	3.31	7.17	11.92	16.81	21.81	26.89
	0.4%	2.99	6.30	10.40	14.59	18.87	23.23
V1	0.05 l m^{-2}	1.26	2.56	4.17	5.83	7.55	9.56
	0.10 l m^{-2}	1.19	2.38	3.84	5.35	6.91	8.51
V2	0.05 l m^{-2}	1.37	2.90	4.79	6.77	8.80	10.90
	0.10 l m^{-2}	0.83	1.69	2.71	3.85	5.03	6.24
V3	0.05 l m^{-2}	1.37	2.83	4.79	6.61	8.48	10.39
	0.10 l m^{-2}	0.83	1.71	2.90	4.02	5.20	6.42
F.E.	0.2 l m^{-2}	0.69	1.37	2.21	3.12	4.06	5.06
	0.4 l m^{-2}	0.63	1.30	2.11	3.00	3.93	4.90
B.E.	0.5 l m^{-2}	0.90	1.88	3.08	4.40	5.75	7.16
	1.0 l m^{-2}	0.50	1.08	1.79	2.59	3.44	4.31
Aq1	0.33%	2.59	5.62	9.37	13.43	17.47	21.58
	0.66%	2.42	5.28	8.90	12.67	16.51	20.44
Control		2.61	5.63	9.40	13.41	17.49	21.63
Max. air-temp.		27.00	24.00	26.50	26.50	26.50	26.00
Min. air-temp.		21.50	19.00	17.50	17.00	17.50	18.00

* All (%) are on the base of air-dry sand.

FIG. 5.47: EFFECT OF VARIOUS CHEMICAL STABILIZERS ON CUMULATED EVAPORATION THROUGH CAPILLARY RISE FROM DRURIDGE BAY SAND SAMPLES AFTER SIX DAYS OF APPLICATION



3. The air-temperature controlled both water evaporation rate and cumulated evaporation from all samples.
4. The reduction in water evaporation from the saturated sand samples were very high with F.E. (0.4 l $m^{-2}$and 0.2 l m^{-2}) and B.E. (1.0 l $m^{-2}$and 0.5 l m^{-2}); high with the higher concentrations of PVA1; PVA2; V1 and Aq1 treatments. Whereas the chemicals PEG3 and PEG4 slightly increased both the evaporation rate and the cumulated evaporation from the sand.
5. The effect of chemical stabilizers on the reduction of water evaporation from Druridge Bay sand through the capillary rise process can be arranged in the following order:

   F.E. > B.E. > V2 > V3 > V1 > PVA1 > PVA2 > Aq1 > Control.

5.1.5 Effect of Soil Chemical Stabilizers on the Formation and the Stability of Druridge Bay Dune Sand Aggregates (Wet and Dry Aggregates)

5.1.5.1 Theoretical Basis

A soil aggregate is a group of two or more primary particles which cohere or bond to each other more strongly than to surrounding particles. The coherence or bonding between the individual particles usually happens by means of cementing agents like organic matter, polymers, hydroxides, etc. (Kemper and Chepil, 1965; and Bolt and Koenigs, 1972).

The stability of soil surface aggregates is of great importance, especially in soils subjected to wind and water erosion, because they always recieve the greatest disruptive energies (Lynch and Bragg, 1985).

Kemper and Koch (1966), Harris et al. (1966), Weeraratna (1976), and Al-Kubaisi (1982), all agree that many factors control the formation and degredation of soil aggregates eg. organic matter content (Rost and Rowles, 1940; Elson and Azar, 1942; Martin, 1945; 1946; Strickling, 1950; Jamison, 1952; Heinonen, 1955; Biswas et al., 1970; and Dekimpe and Mehuys, 1979), alkaline-earth carbonates (De Boodt et al, 1961; Burgland, 1971; and Toogood, 1978), cultivation practices, including irrigation and the quality of irrigation water, and plant species, etc (Tisdal and Oades, 1979), exchangeable sodium, calcium and magnesium cations (Peterson, 1946; Aldrich and Martin, 1954; Klages, 1966; El-Swaify, 1969; El-Swaify et al., 1970; Emerson, 1970; Kijne and Bishay, 1974; and Chi and Emerson, 1977), presence of amorphous sesquioxides and silicates (Lutz, 1936; Weldon and Hide, 1942; and Churchman and Tate, 1987), type and amount of clay minerals (Page and Robinson, 1950; Mazurak, 1950; Chesters et al., 1957; Koznetsova, 1966; Saini et al., 1966; Velaso-Molina et al., 1971; Vandevelde and De Boodt, 1972; and Dowdy, 1975), initial moisture content and the air-trapped in the centre

of a relatively dry soil aggregates during wetting (Nijhawan and Olmstead, 1947; Alderfer, 1950; Emerson, 1954; Emerson and Grundy, 1954; Baver et al., 1972; Bolt and Koenigs, 1972; Rigol and De Bisschop, 1972; Gabriels and De Boodt, 1972; 1974; and Tayel and El-Hady, 1981a), and micro-organisms (Tisdall and Oades, 1979).

Application of the chemical materials as soil conditioners or stabilizers can play a considerable role in the formation and the stabilization of soils aggregates (Hubbel and Stubblefield, 1948; Allison, 1952; Allison and Moore, 1956; Mortonson and Martin, 1957; Ahuja and Swatzendruber, 1972; De Boodt, 1972; Gabriels, 1972; Moldenhauer and Gabriels, 1972; Hartmann et al., 1975; Oades, 1976; Tayel and Anter, 1978; Yousif et al., 1978; and Page, 1979). For example, Hartmann et al. (1975) found that the aggregate stability of sandy and silty loam soils was improved by means of a series of soil conditioners including (0.2%) polyvinyl alcohol (PVA), (0.2%) polyacrylamide (PAM), and (0.8%) bituminous emulsion (all percentages are based on dry soil weight). Hartmann et al. also mentioned, that the low stability of the sandy aggregates treated with PVA could be ascribed to the fact that the polymer was leached during the wet sieving, at a time when this phenomenon didn't occur with PAM where the adsorption of the polymer was made irreversible by the cross-linker glyoxal (Huylebroeck, 1973).

Pla (1975) found that the surface samples representing six different soils from Venezuela treated with 0.16% PAM and 1.25% bituminous emulsion (on dry weight bases) had more and larger water stable aggregates.

Treatment of a simulated sodic and natural sandy loam soils with polyvinyl acetate (PVAc) emulsions at rates from 0.03% to 0.12% by weight, increased the stability of the aggregates at all rates (Carr and Greenland, 1975).

Szczypa et al. (1976) found that the volume of water stable aggregates of a sandy soil increased as the concentration of Gigtar-s soil conditioner (its active substance was partly hydrolized polyacrylamide) increased.

Polymers-kriliums were found to be extremely effective aggregators when applied to sod-podzolic and high-chesnut soils (Kachinsky and Mosolova, 1976).

De Waele (1976a) illustrated that 1 litre of bituminous emulsion diluted by 5 litres of water per m^2 had a positive effect on the aggregate stability of a saline clayey soil from Tunisia. The optimal stabilization in the laboratory test was for the rate 1.25 l m^{-2}diluted 10 times with water.

Conditioning sandy soil from Egypt with 0.5%; 1.0% and 1.5% bituminous emulsion, 0.25%; 0.5% and 1.0% curasol, and 0.05%; 0.1% and 0.2% polyacrylamide with glyoxal as a cross linker enhanced the formation of water stable aggregates > 4 mm > 2 mm > 0.84 mm and > 0.25 mm in diameter. 1.0% Concentrations of either bituminous emulsion or curasol AH and 0.2% PAM + glyoxal were recommended (Tayel and El-Hady, 1981b). In another study by El-Hady and Tayel (1981), conditioning of calcareous soil with bituminous emulsion (0.5, 1.0 and 1.5 gm per 100 gm soil) increased the mean weight diameter (MWD)* and decreased the stability index (SI)**. The change in these two parameters varied with the amount of bituminous emulsion applied.

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* *Mean Weight Diameter (MWD) as indicated by Van Bavel (1950) is as follows:-*

$$MWD = \sum_{i=1}^{n} XiWi$$

Xi = the mean diameter of each size fraction,

Wi = the proportion of the total sample weight occurring in the corresponding size fraction. The summation is carried out over all n size fractions, including the one that passes through the first sieve.

** *Stability Index (SI): The difference between the mean weight diameter of the dry aggregate distribution and the wet stable aggregate distribution is defined as the stability index (SI) (Hartmann et al. 1975). The smaller the stability index the better is the water stability of the aggregates.*

5.1.5.2 Techniques, Materials and Methods

The effect of soil conditioners on the stability of Druridge Bay sand aggregates was investigated under laboratory and greenhouse conditions. The soil conditioners used were PVA1; PVA2; PEG3; PEG4; V1; V2; V3; B.E.; F.E.; Aq1 and Aq2* (tables 4.1 and 4.2). All the chemicals were prepared or diluted with water to produce the concentrations mentioned in table (4.2) when applied at a rate of 6.0 l m^{-2}. The aggregate stability tests were carried out on two treatments:-

1. Samples of 300 gm were collected from the surface of sand samples in pots which had been treated with stabilizers 405 days previously and in which *Eucalyptus microtheca* was growing.
2. Samples of 100 gm (air-dry sand) treated with the various chemicals and tested 3 days after treatment.

The dry and wet aggregate stability of various treatments was determined as follows:-

1. Dry Aggregates:

Sand aggregation was determined by dry sieving on a nest of sieves and by weighting the amount of sand retained. The set of sieves used covered particle diameters of: 0.21 mm; 0.50 mm; 1.18 mm; 2.00 mm; and 4.76 mm. This set of sieves was chosen as it has already been used by (Yoder, 1939; and Youker and McGuinness, 1957). It also includes a good range of particles sizes; small sizes which give a good idea about the distribution of sand particles within the control sand samples and large sizes (> 2.0 mm in diameter) which have a good ability to withstand wind erosion. In this study, all treatments were tested in duplicates. The samples were shaken for 5 minutes, after which the sand retained on each sieve was weighed, and the percentages retained was calculated on the basis of

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* *As explained previously the late availability of Aq2 meant that it was not used in the 405 day experiment.*

the total air-dry sand sample used. These percentages were later used for the calculation of the mean weight-diameter (MWD) of the dry aggregates following the method and the equation introduced by Youker and McGuinness (1957) as in (table 5.34):

Table 5.34: The Method of Determining Mean Weight Diameter Value by Computing Method (After Youker and McGuinness, 1957)

Size Range (mm)	Per Cent Retained	Midpoint of Range	Product of Midpoint and Per Cent Retained
0.0 - 0.2	49.9	0.10	0.04990
0.2 - 0.5	17.4	0.35	0.06090
0.5 - 1.0	11.5	0.75	0.08625
1.0 - 2.0	8.6	1.50	0.12900
2.0 - 8.0	12.6	5.00	0.63000
			.....
			0.95605

0.95605 is the calcualated mean weight-diameter for the above illustrated aggregate percentage data. The equation to calculate the actual mean weight-diameter is:

$Y = 0.876X - 0.079$

X = the calculated mean weight diameter,

Y = the actual mean weight-diameter.

The summation ($\sum_{i=1}^{n}$ Xi Wi) used for the calculation of the calculated MWD is carried out over all n size fractions, including the one that passes through the first sieve (Van Bavel, 1950).

2. Wet Aggregates:

Water stability of the aggregates was determined by the sieving samples

through the same set of sieves as for dry aggregates but this time immersed in water, using the method of De Leenheer and De Boodt (1967). All tests were duplicate.

A major factor affecting the size of the water stable aggregates is the method by which they are wetted (Kemper and Chepil, 1965). Kemper and Chepil (1965) indicated that if the purpose of the aggregate analysis is related to the formation of soil crusts, immersion wetting is probably the preferred procedure. Therefore, the sand samples were immersed with care in water.

Once more, the samples were shaken for 5 minutes, after which the sand retained on each sieve was collected in beakers and then oven-dried at (60°C). The oven-dry weight percentages were used for the calculation of mean weight diameter of the water stable aggregates.

Assuming that the aggregates which are not able to withstand the air-dry sieving are not able to withstand the underwater sieving, a slightly different method than the one used by Hartmann et al. (1975) was followed here for the determination of the aggregate stability index (SI), since the same samples, which had already been tested for the air-dry aggregates measurement, were used in this test. This method was derived from the following equation:

$$\%SI = \frac{Wt1 - (Wt2 - Wt3)}{Wt1} \times 100\%$$

in which:

Wt1 = Wt. of the sample used,

Wt2 = Wt. of water stable aggregates, and

Wt3 = Wt. of the unaggregated sand.

Percentages could be used instead of the weights in the above equation. Water stable aggregates of > 0.5 mm in diameter were used in the above mentioned equation, as the size (> 0.5 mm) represents the perfect stable aggregates in Druridge Bay sand, since 99.4% of the particles in the untreated Druridge sand

are < 0.5 mm in diameters depending on the particles sizes analysis.

Since the method of determining the stability index is in fact a determination of aggregate instability in water, the bigger the change, the more unstable the aggregates are (De Leenheer and De Boodt, 1967). Consequently, the smaller the values of SI%, the more stable are the aggregates.

5.1.5.3 Results, Statistical Analysis and Discussions

Tables (5.35 - 5.38) illustrate the percentages of the different sizes of air-dry and water stable aggregates from both the 3 day and 405 day treatments for the control and the various chemical stabilizers used.

It is obvious that the untreated Druridge sand is structureless. It does not give more than 0.89% of aggregates > 0.5 mm in diameter in the test of the air-dry aggregation. In the water stable aggregation test, only 0.60% of the aggregates in the control were sized > 0.5 mm. These were not infact actual aggregates as the Druridge sand already contains about 0.60% of individual sand particles > 0.5 mm.

Cultivation of sand with Eucalyptus for 405 days increased the formation of sand aggregates > 0.5 mm in both dry and wet aggregation tests of the control. This was probably due to the increases in both microbial activities and the organic contents coming from the decomposition of Eucalyptus leaves and roots.

All the chemical treatments except PEG3 and PEG4 in the 3 day samples, increased the percentage of aggregates > 4.76 mm. The percentages ranged between 95.24% for the Aq1 0.66% to 1.46% for the F.E. 0.2 l m^{-2} in the dry aggregation test. In the water stable aggregation test on the 3 day treatment, Aq1 0.66% followed by Aq2 250 gm m^{-2}; Aq2 200 gm m^{-2}; B.E. 1.0 l m^{-2}; Aq1 0.33% and PVA1 0.4% were the only treatments that gave more than 20% of > 4.76 mm aggregates (95.21%, 69.51%, 40.37%, 34.80%, 24.45%, and 20.47% respectively). The wetting process caused considerable disruption of the previously dry aggre-

Table 5.35: Air-Dry Stable Aggregates in Druridge Bay Sand as Affected by Soil Chemical Stabilizers (3 Days After Treatment Samples).

Treats	Conc.*	Aggregates Percentages (%)					
		< 0.21	0.21-0.50	0.50-1.18	1.18-2.00	2.00-4.76	> 4.76
PVA1	0.2%	11.70	71.49	2.30	0.62	0.70	13.10
	0.4%	7.87	58.57	5.06	1.00	2.47	25.03
PVA2	0.2%	9.40	63.50	9.19	2.08	2.48	13.35
	0.4%	7.62	47.28	9.09	3.19	6.68	26.14
PEG3	0.2%	13.39	85.35	1.26			
	0.4%	13.22	85.22	1.55	0.01		
PEG4	0.2%	12.71	86.32	0.94	0.03		
	0.4%	11.77	86.88	1.30	0.05		
V1	0.05 l m^{-2}	7.59	78.12	8.28	1.17	2.38	2.46
	0.10 l m^{-2}	3.99	48.46	13.84	2.56	5.63	25.51
V2	0.05 l m^{-2}	7.41	70.04	5.64	0.87	4.21	11.83
	0.10 l m^{-2}	3.25	32.54	5.24	1.40	3.17	54.41
V3	0.05 l m^{-2}	11.46	77.95	3.80	0.25	0.34	6.19
	0.10 l m^{-2}	3.57	70.30	7.94	1.35	1.19	15.66
F.E.	0.2 l m^{-2}	11.35	74.69	6.81	3.72	1.97	1.46
	0.4 l m^{-2}	10.47	62.81	11.77	1.17	0.48	13.30
B.E.	0.5 l m^{-2}	8.12	64.33	11.21	3.55	6.39	6.39
	1.0 l m^{-2}	1.02	32.29	10.85	4.83	11.76	39.25
Aq1	0.33%	9.97	62.81	1.77	0.50	0.28	24.66
	0.66%	0.31	0.80	0.96	0.84	1.85	95.24
Aq2	200 gm m^{-2}	4.50	38.76	7.93	1.78	1.60	45.44
	250 gm m^{-2}	0.76	10.35	5.30	0.62	1.04	84.58
Control		15.12	84.00	0.89			

* All (%) are on the base of air-dry sand.

Table 5.36: Water Stable Aggregates in Druridge Bay Sand as Affected by Soil Chemical Stabilizers (3 Days After Treatment Samples).

Treats	Conc.*	Aggregates Percentages (%)					
		< 0.21	0.21-0.50	0.50-1.18	1.18-2.00	2.00-4.76	> 4.76
PVA1	0.2%	13.51	75.55	0.97	0.18	1.24	8.55
	0.4%	8.75	67.54	1.53	0.10	1.61	20.47
PVA2	0.2%	12.67	79.01	1.15	0.20	0.39	6.58
	0.4%	13.35	74.58	1.01	0.12	0.24	10.70
PEG3	0.2%	13.69	85.39	0.92			
	0.4%	13.34	85.57	1.09			
PEG4	0.2%	13.85	85.32	0.83			
	0.4%	13.83	85.22	0.93	0.02		
V1	0.05 l m^{-2}	9.63	82.84	6.58	0.89	0.06	
	0.10 l m^{-2}	4.86	71.43	17.05	3.56	2.41	0.69
V2	0.05 l m^{-2}	8.60	87.79	3.47	0.12	0.02	
	0.10 l m^{-2}	6.75	75.16	12.54	2.36	2.87	0.32
V3	0.05 l m^{-2}	13.78	79.05	1.84	0.22	0.50	4.61
	0.10 l m^{-2}	9.97	74.44	2.90	0.26	0.27	12.16
F.E.	0.2 l m^{-2}	15.27	71.80	5.81	3.95	2.69	0.48
	0.4 l m^{-2}	11.31	63.70	10.20	1.99	0.52	12.28
B.E.	0.5 l m^{-2}	9.17	64.39	11.09	3.65	5.96	5.74
	1.0 l m^{-2}	3.72	30.32	10.30	5.70	15.16	34.80
Aq1	0.33%	10.30	63.88	1.13	0.19	0.05	24.45
	0.66%	0.75	1.64	0.85	0.52	1.03	95.21
Aq2	200 gm m^{-2}	5.21	51.97	2.16	0.25	0.04	40.37
	250 gm m^{-2}	4.73	20.43	3.23	1.04	1.06	69.51
Control		16.74	82.66	0.60			

* All (%) are on the base of air-dry sand.

Table 5.37: Air-Dry Stable Aggregates in Druridge Bay Sand as Affected by Soil Chemical Stabilizers (405 Days After Treatment Samples).

Treats	Conc.*	Aggregates Percentages (%)					
		< 0.21	0.21-0.50	0.50-1.18	1.18-2.00	2.00-4.76	> 4.76
PVA1	0.2%	5.05	87.91	4.54	0.94	1.02	0.55
	0.4%	4.54	86.01	4.66	1.37	1.99	1.43
PVA2	0.2%	4.90	86.54	3.64	0.82	1.89	2.21
	0.4%	6.38	83.66	2.43	0.71	2.75	4.07
PEG3	0.2%	5.33	89.19	3.44	0.58	1.02	0.44
	0.4%	5.51	86.82	4.25	1.28	1.27	0.87
PEG4	0.2%	5.73	92.35	1.85	0.06	0.01	
	0.4%	5.65	87.01	4.64	0.95	0.95	0.80
V1	0.05 l m^{-2}	4.77	93.84	1.28	0.01	0.10	
	0.10 l m^{-2}	4.37	93.96	1.50	0.04	0.13	
V2	0.05 l m^{-2}	4.97	93.25	1.65	0.06	0.04	0.03
	0.10 l m^{-2}	4.74	93.48	1.59	0.07	0.06	0.06
V3	0.05 l m^{-2}	5.07	88.70	2.88	0.58	1.38	1.39
	0.10 l m^{-2}	3.89	89.27	2.93	1.11	1.38	1.42
F.E.	0.2 l m^{-2}	4.55	93.38	1.70	0.20	0.13	0.04
	0.4 l m^{-2}	2.73	92.02	4.29	0.72	0.16	0.08
B.E.	0.5 l m^{-2}	4.47	72.06	15.58	2.52	0.88	4.49
	1.0 l m^{-2}	2.32	17.04	28.80	6.04	16.10	29.70
Aq1	0.33%	5.55	89.51	3.22	0.72	0.64	0.36
	0.66%	1.76	10.09	5.41	2.75	1.27	78.72
Control		5.85	91.43	2.08	0.34	0.24	0.06

* All (%) are on the base of air-dry sand.

Table 5.38: Water Stable Aggregates in Druridge Bay Sand as Affected by Soil Chemical Stabilizers (405 Days After Treatment Samples).

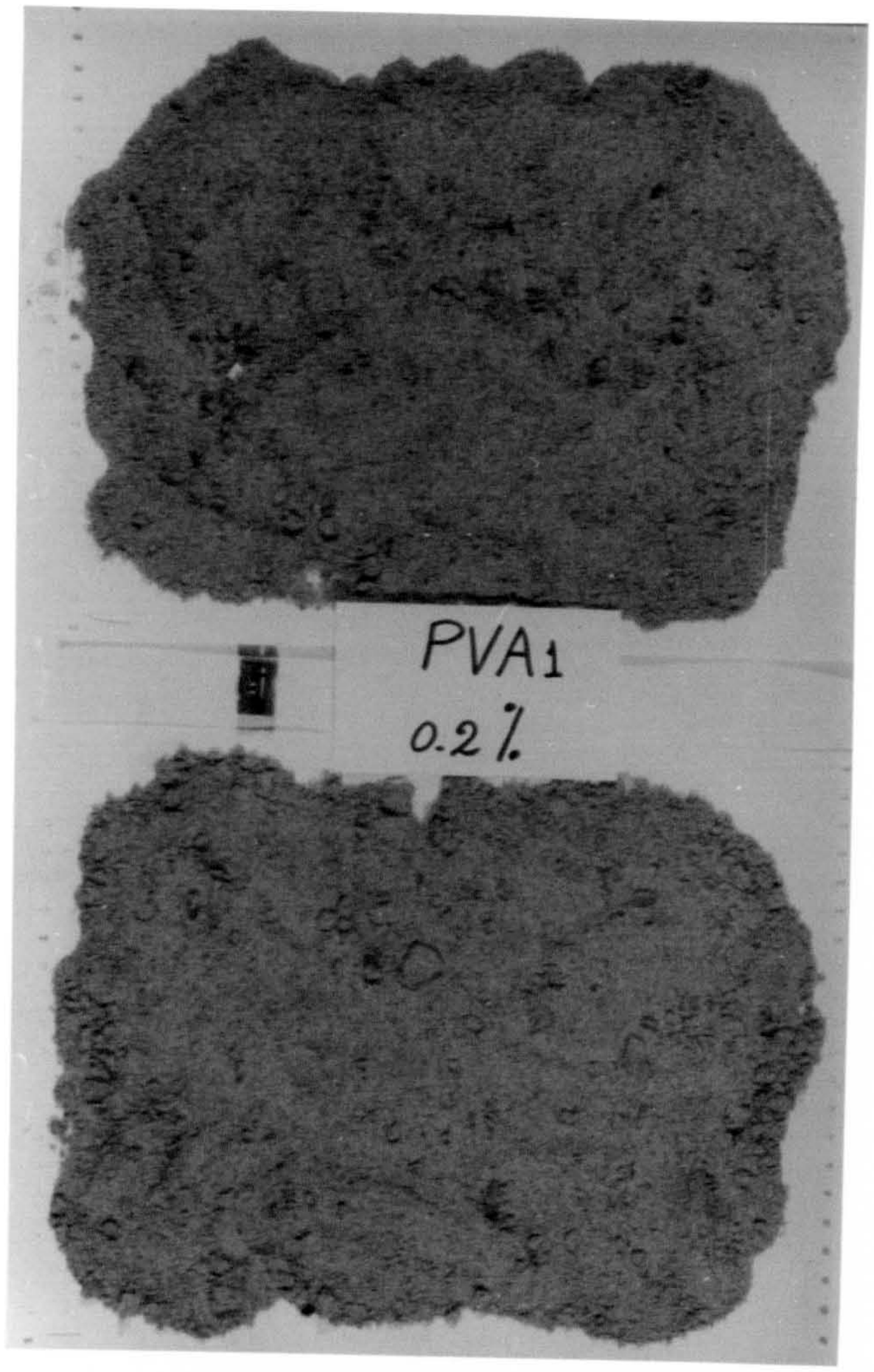
Treats	Conc.*	Aggregates Percentages (%)					
		< 0.21	0.21-0.50	0.50-1.18	1.18-2.00	2.00-4.76	> 4.76
PVA1	0.2%	6.25	89.31	2.47	0.74	0.93	0.30
	0.4%	10.84	81.22	3.94	1.24	2.00	0.76
PVA2	0.2%	8.54	84.12	3.12	0.76	1.92	1.54
	0.4%	8.85	82.14	2.29	0.66	3.25	2.81
PEG3	0.2%	7.56	87.79	2.94	0.54	0.99	0.18
	0.4%	7.90	85.52	3.71	1.12	1.35	0.40
PEG4	0.2%	8.34	90.40	1.20	0.05	0.01	
	0.4%	6.81	86.08	4.46	1.52	0.88	0.25
V1	0.05 l m^{-2}	7.87	90.80	1.30	0.02	0.01	
	0.10 l m^{-2}	8.66	90.09	1.10	0.12	0.03	
V2	0.05 l m^{-2}	11.20	87.39	1.35	0.03	0.03	
	0.10 l m^{-2}	11.08	87.16	1.66	0.05	0.05	
V3	0.05 l m^{-2}	10.44	84.67	2.03	0.46	1.55	0.85
	0.10 l m^{-2}	9.64	83.70	3.27	0.98	1.38	1.03
F.E.	0.2 l m^{-2}	11.08	86.97	1.61	0.20	0.14	
	0.4 l m^{-2}	6.21	88.70	4.33	0.60	0.15	0.01
B.E.	0.5 l m^{-2}	4.72	72.46	15.77	2.35	1.11	3.59
	1.0 l m^{-2}	2.74	20.23	29.99	7.60	12.38	27.06
Aq1	0.33%	7.06	89.09	2.64	0.54	0.47	0.20
	0.66%	1.83	12.39	5.70	2.63	1.39	76.06
Control		5.95	91.93	1.71	0.23	0.18	

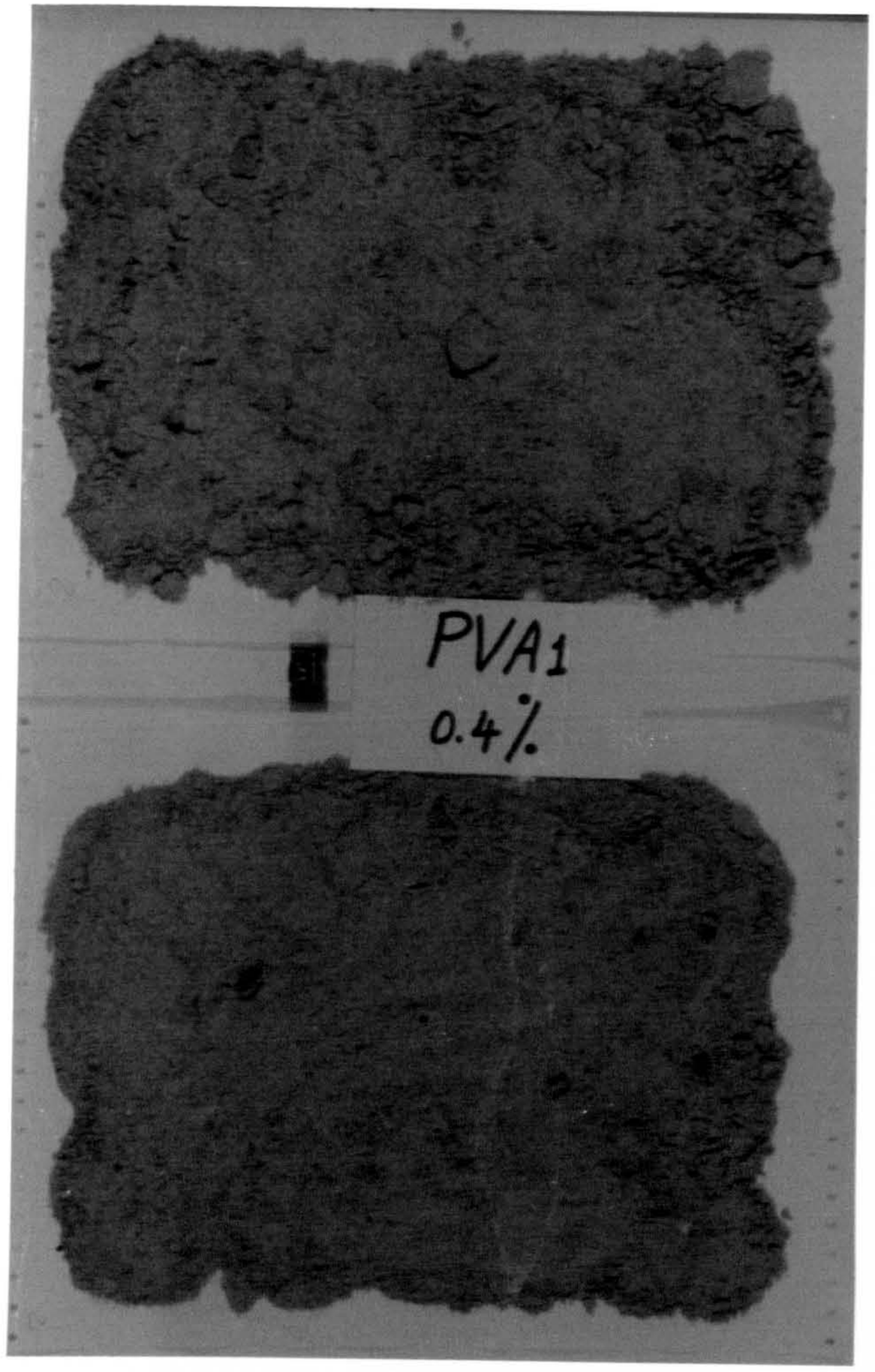
* All (%) are on the base of air-dry sand.

gates (Kemper and Chepil, 1965). Several chemicals including PEG3 (0.2% and 0.4%), PEG4 (0.2% and 0.4%), V1 (0.05 and 0.10 l m^{-2}), V2 (0.05 and 0.10 l m^{-2}) lost almost all their effectiveness as soil aggregate stabilizers, either because they had been leached during the wet sieving (Gabriels and De Boodt, 1974; and Hartmann et al., 1975), or because they produced water vulnerable bonds between the individual sand particles.

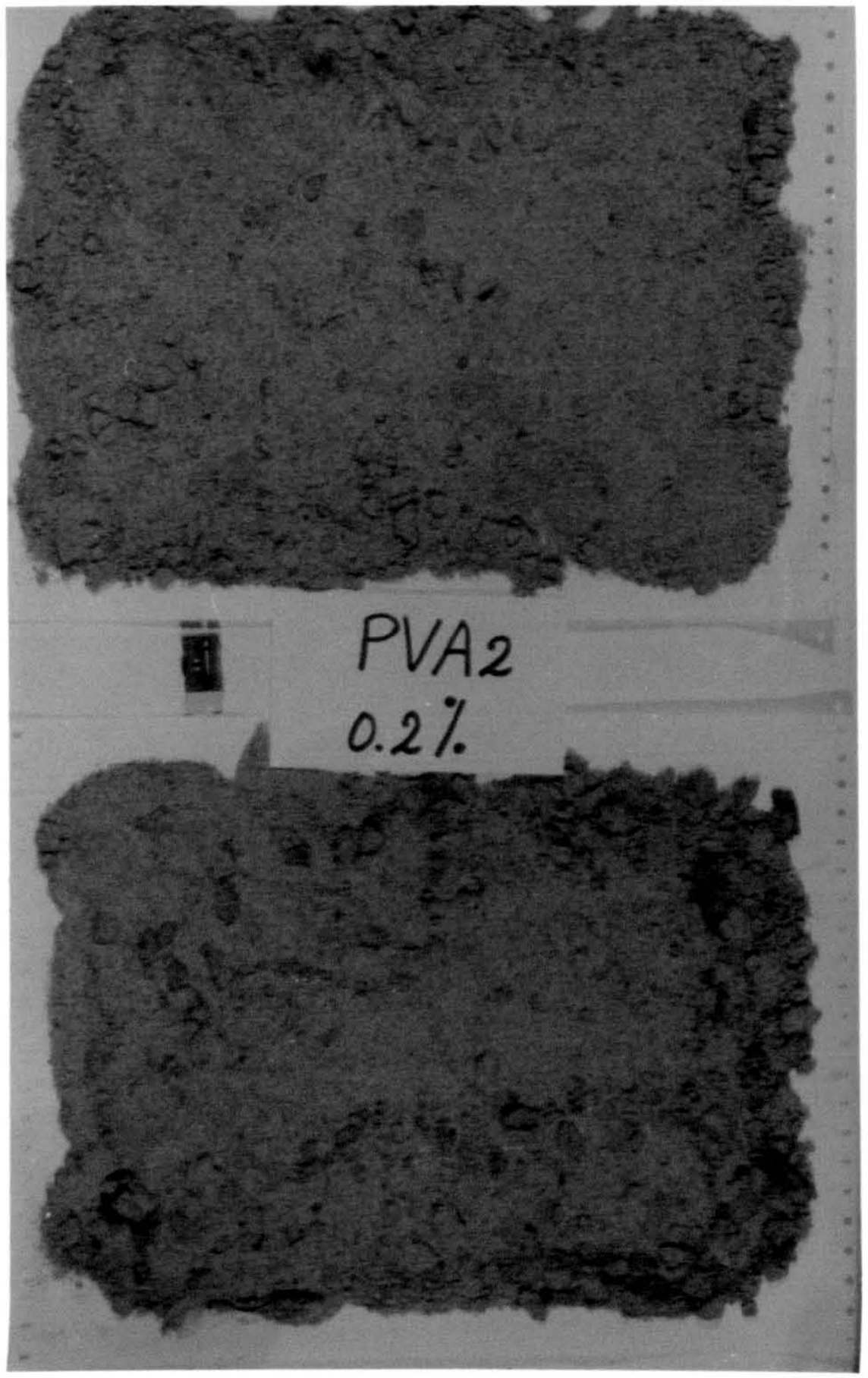
In the 405 day samples with Eucalyptus, Aq1 0.66% once more produced the greatest increase in the stability of the aggregates. It gave an extremely high percentage of > 4.76 aggregates, in both dry and wet sieving. The percentages of the air-dry aggregates > 4.76 for Aq1 0.66%, B.E. 1.0 l m^{-2} and 0.5 l m^{-2}, and PVA2 0.4% were 78.72%, 29.70%, 4.49%, and 4.07% respectively. While the percentages for their water stable aggregates > 4.76 mm were 76.06%; 27.06%; 3.59% and 2.8% respectively. From observations made during the Eucalyptus experiment, it was obvious that within the first three months, all the remaining chemical treatments (i.e. PVA1, PEG3, PEG4, V1, V2 and V3) lost their ability to hold the surface sand particles together as they had either been dissolved in irrigation water and/or only produced weak bonds between the sand particles. One interesting anomaly was noted involving the F.E. treatments. Although both the 0.4 and 0.2 l m^{-2} treatments showed poor long term aggregate stability, visual comparison of the aggregate stability after 405 days suggested that the F.E. surface stability was third only to Aq1 0.66% and B.E. 1.0 and 0.5 l m^{-2}. Thus suggesting that tests of aggregate stability may not in fact always give a true picture of the effectiveness of a chemical treatment (see also chapter 8). Photos (5.3 - 5.23) illustrate some air-dry sand samples from the surface layer of the Eucalyptus (405 day) experiment before the laboratory aggregation tests.

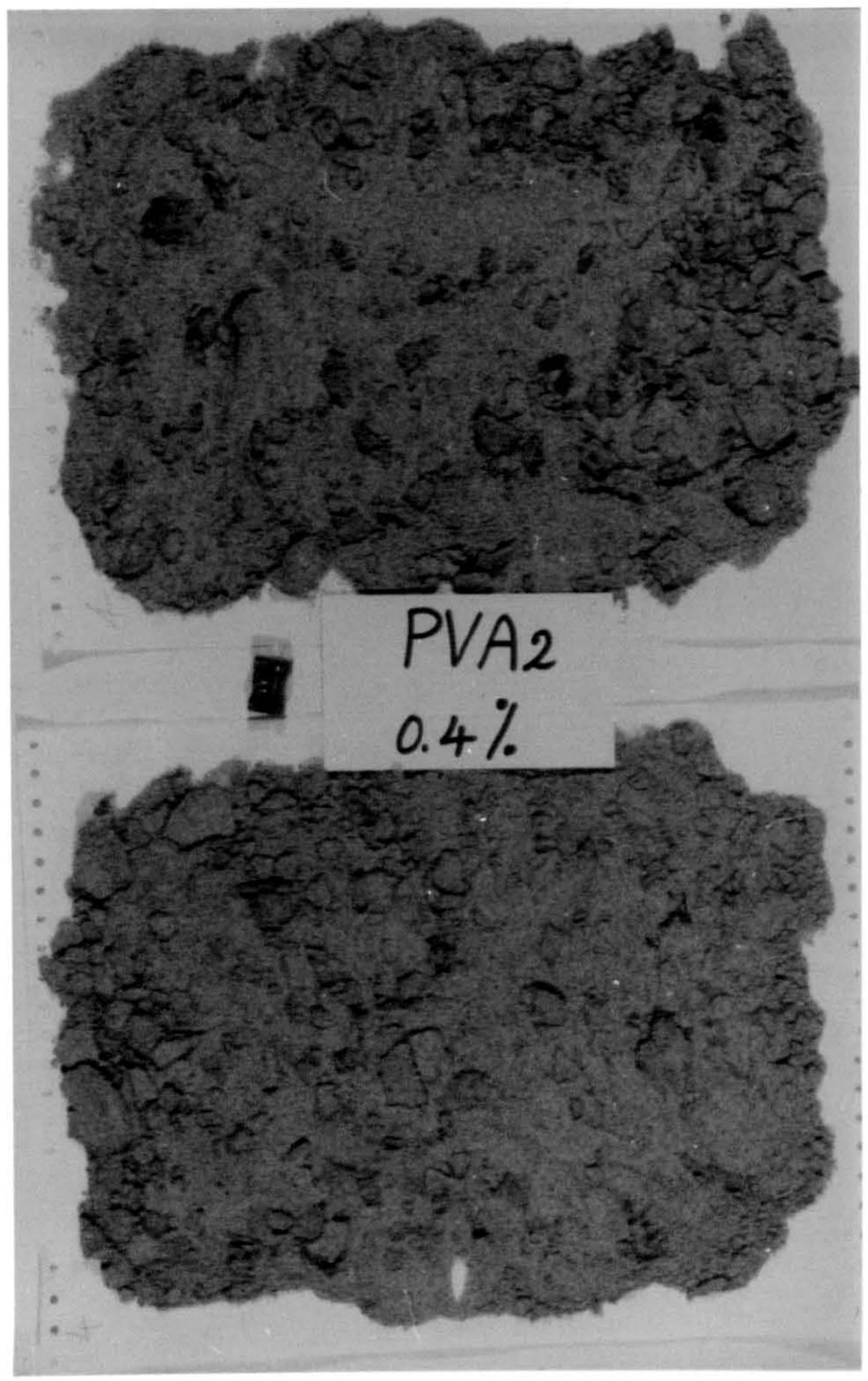
Figures (5.48 - 5.53) and tables (5.39 and 5.40) summarise the effect of the chemical stabilizers on the mean weight-diameter (MWD) of air-dry and water stable aggregates and the aggregate stability index (SI) in Druridge Bay sand



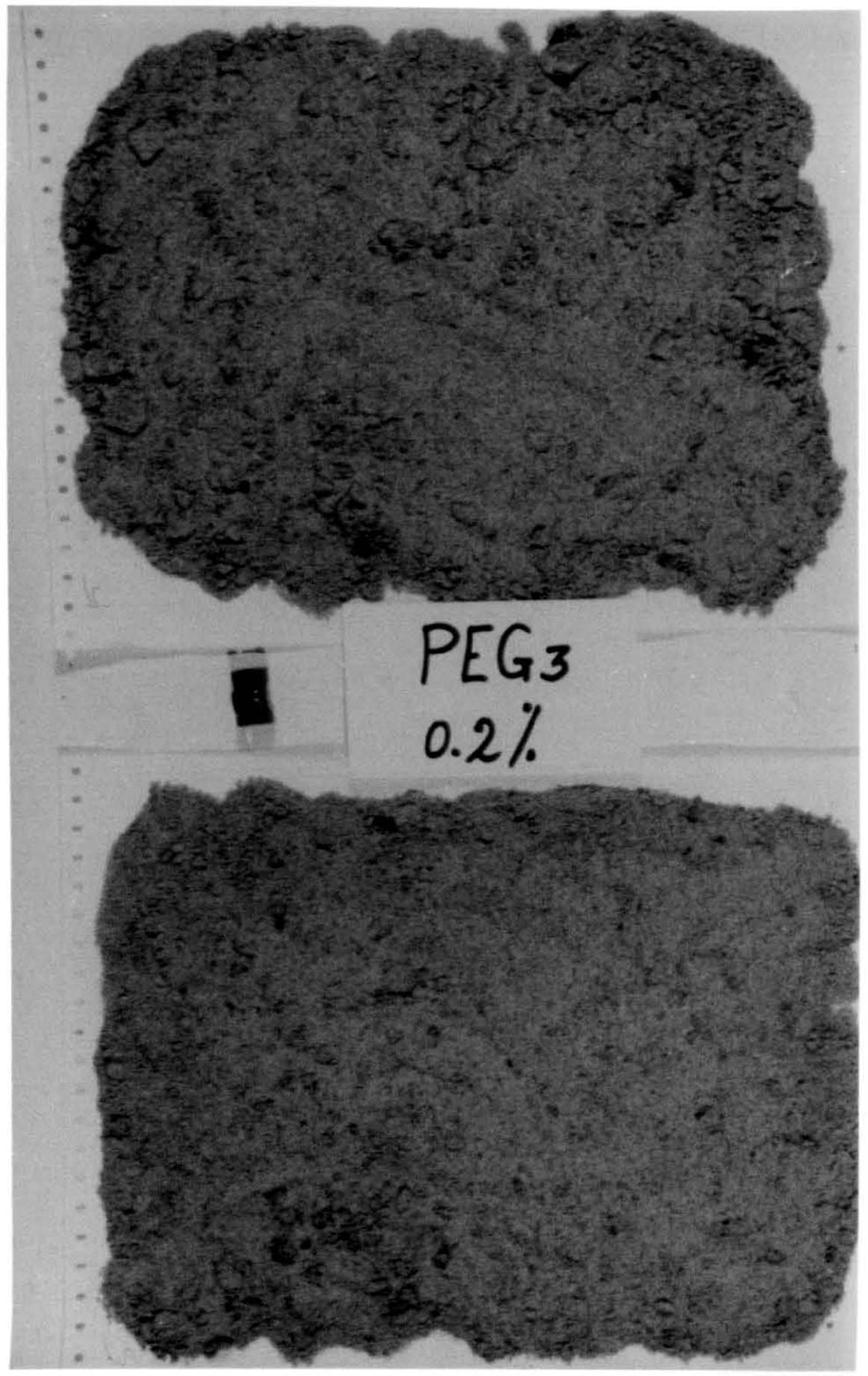


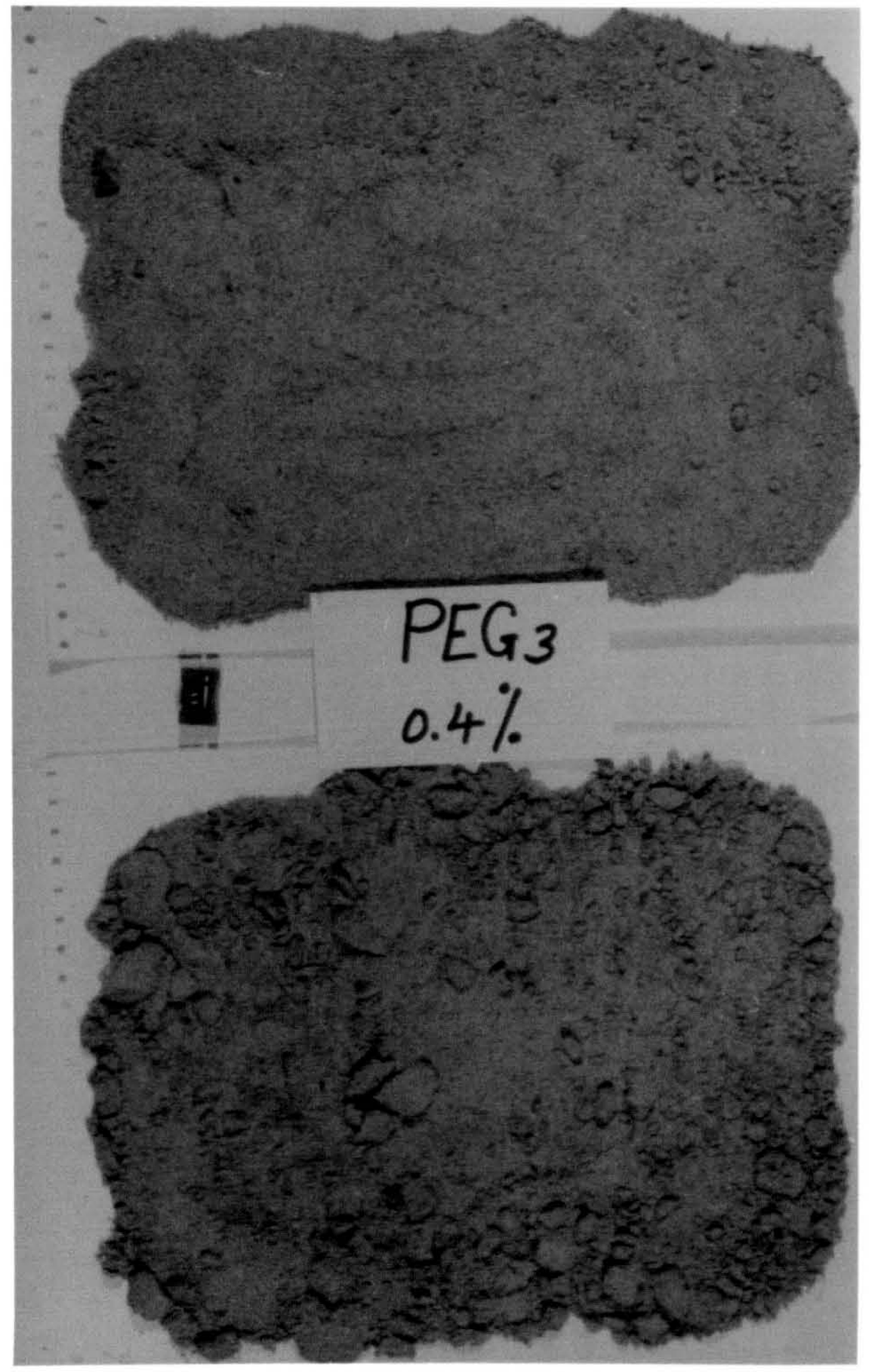
Plates 5.3 & 5.4: Air-Dry Sand Samples From the Surface Layer of the Eucalyptus Experiment (After 405 Days From Treatment With PVA1 0.2% and 0.4%).



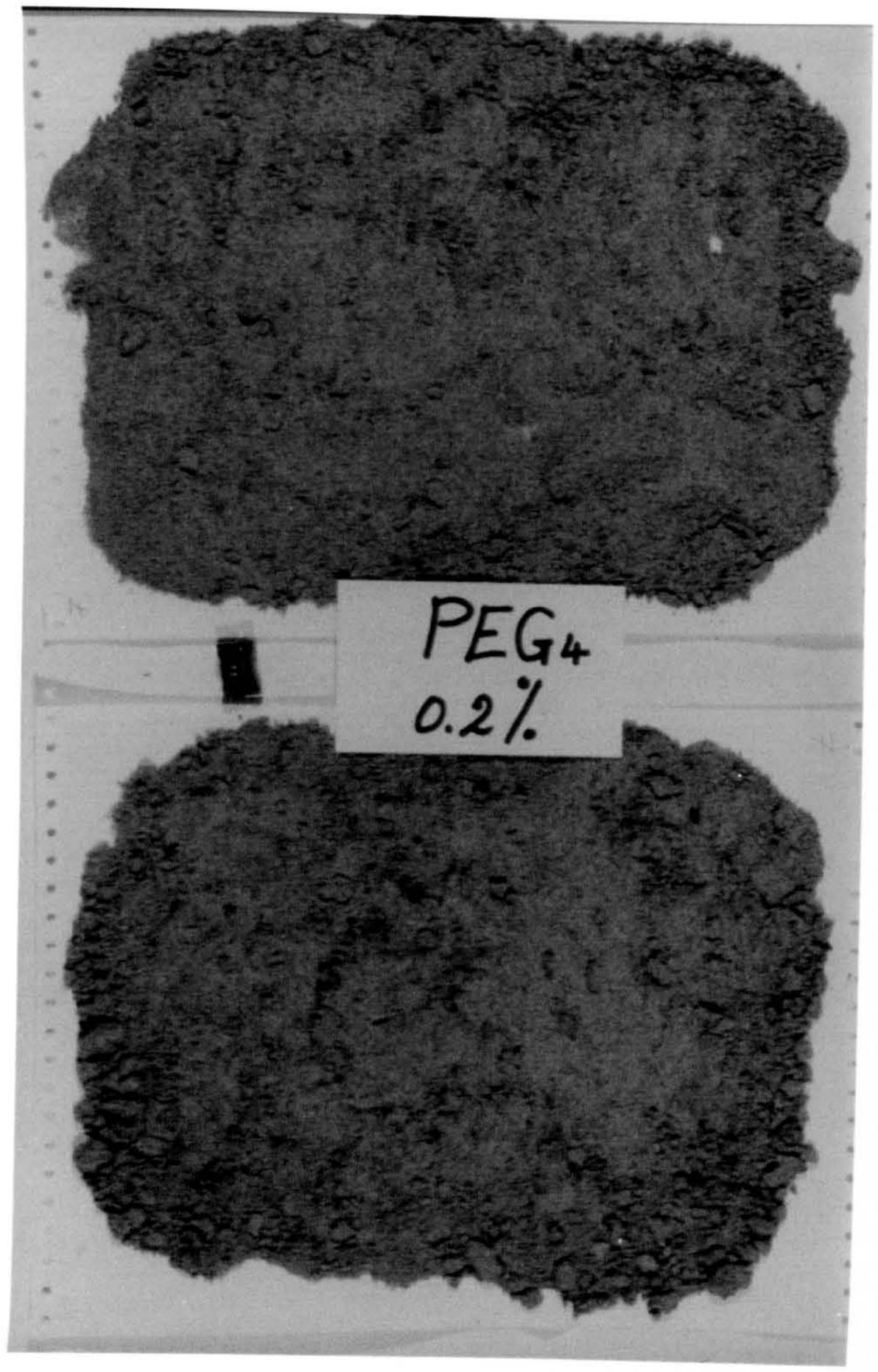


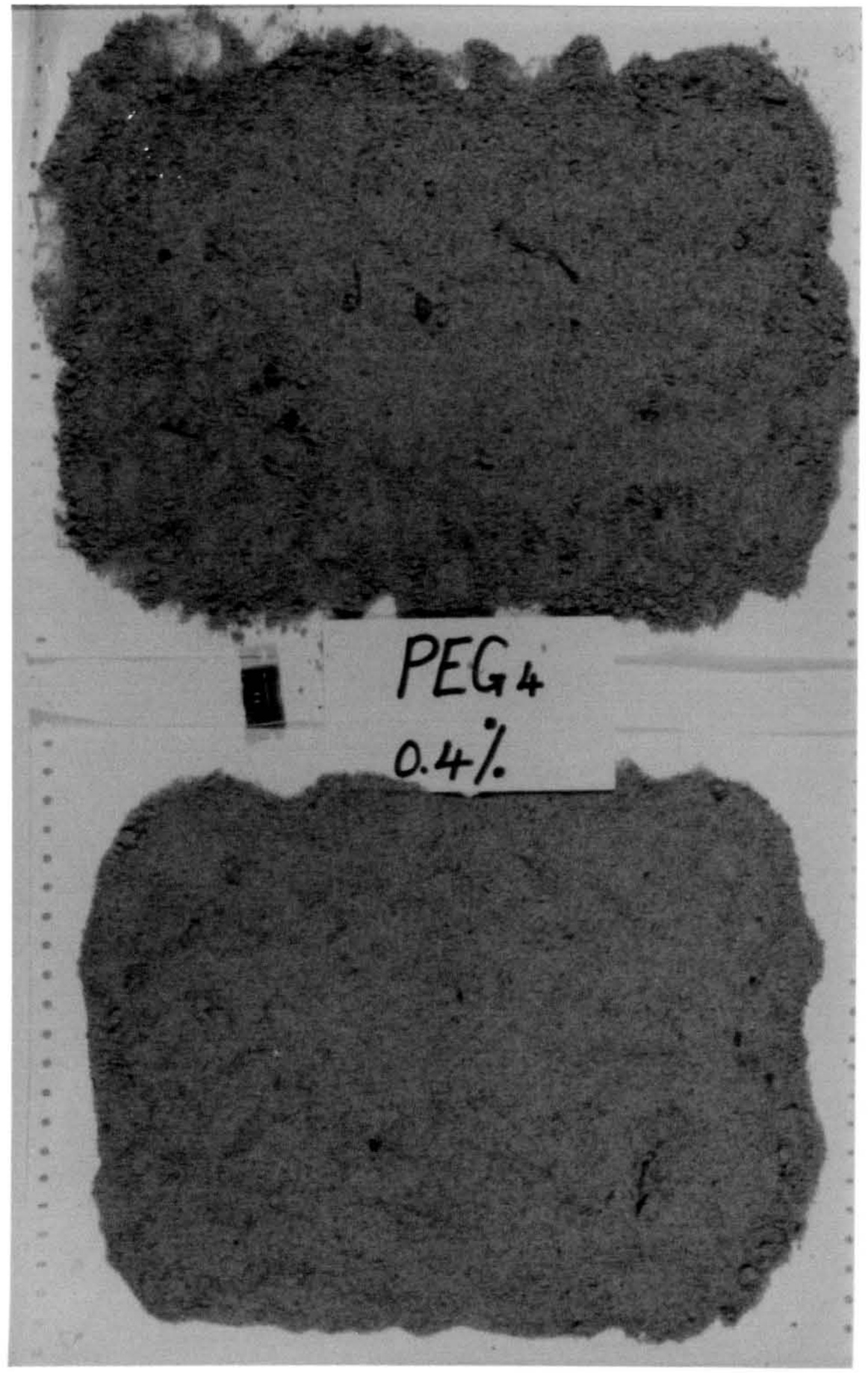
Plates 5.5 & 5.6: Air-Dry Sand Samples From the Surface Layer of the Eucalyptus Experiment (After 405 Days From Treatment With PVA2 0.2% and 0.4%).



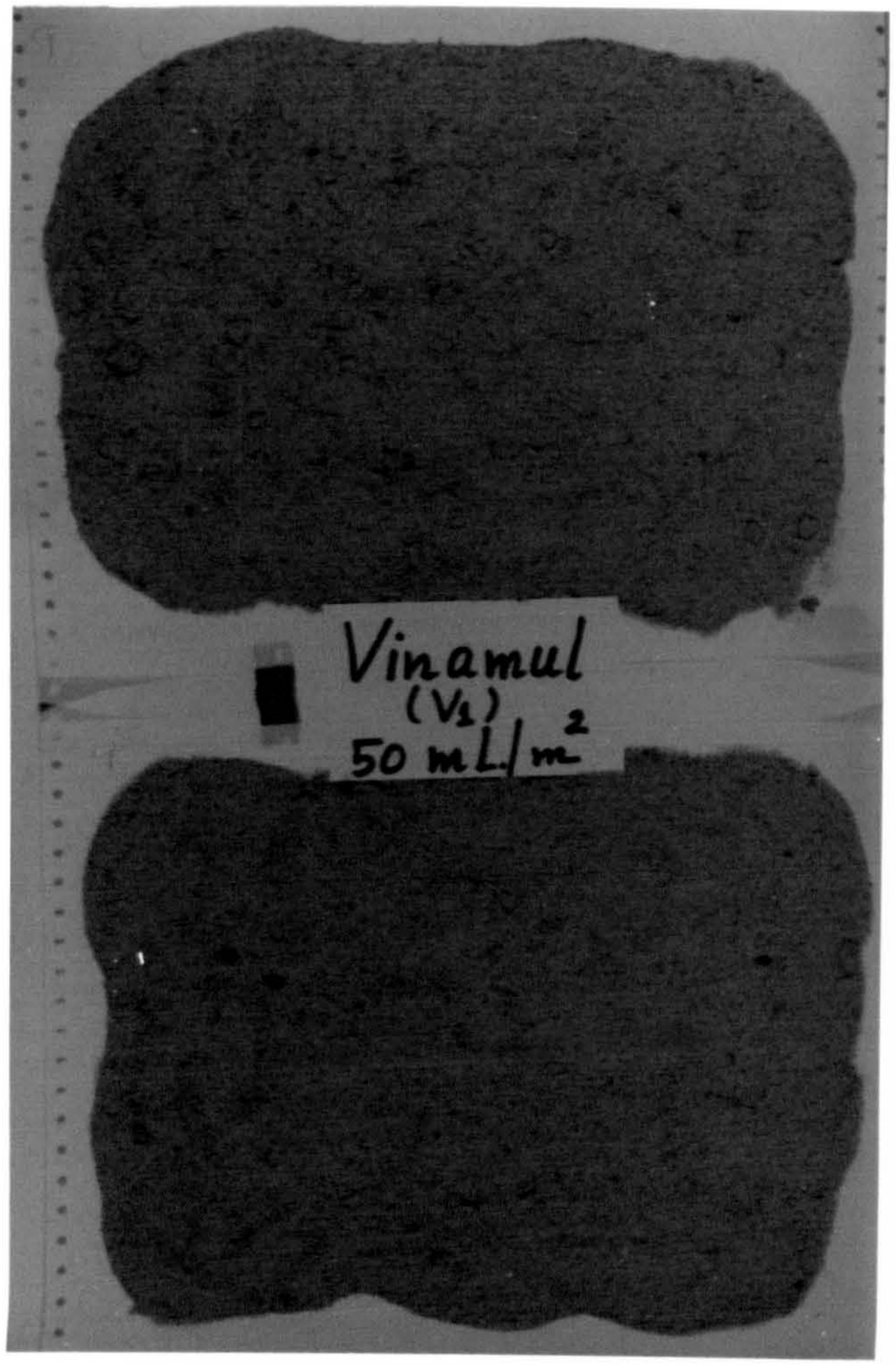


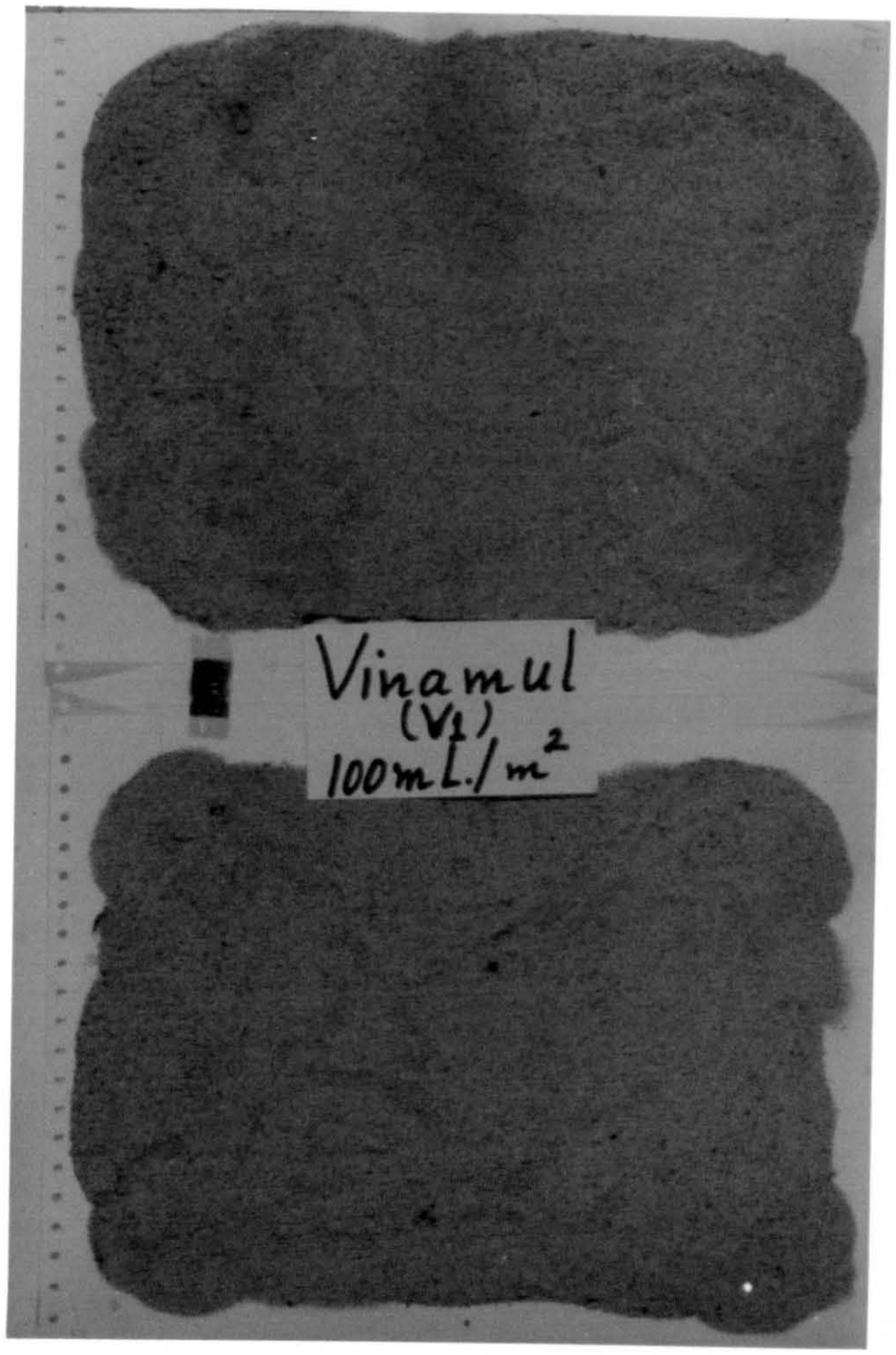
Plates 5.7 & 5.8: Air-Dry Sand Samples From the Surface Layer of the Eucalyptus Experiment (After 405 Days From Treatment With PEG3 0.2% and 0.4%).



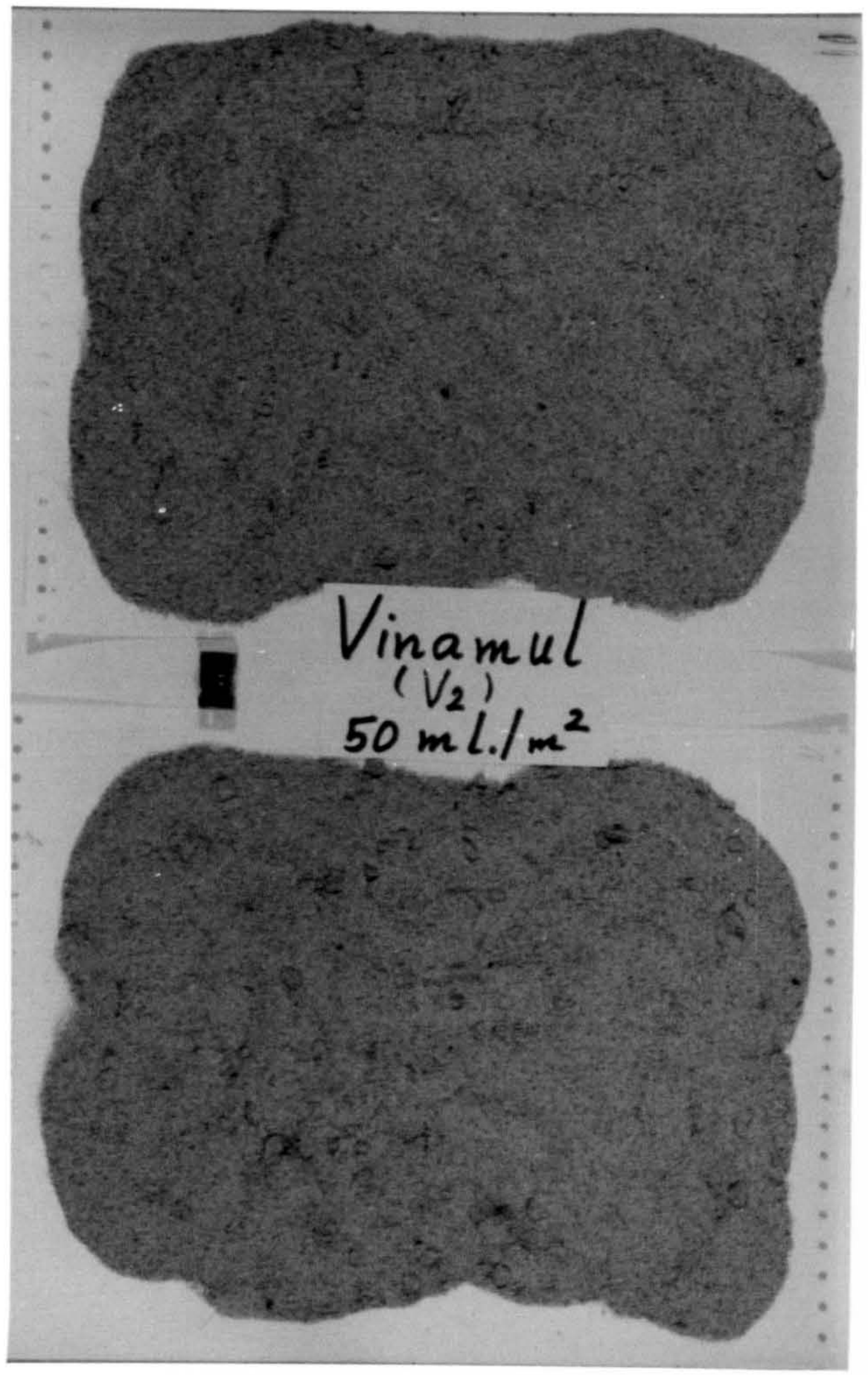


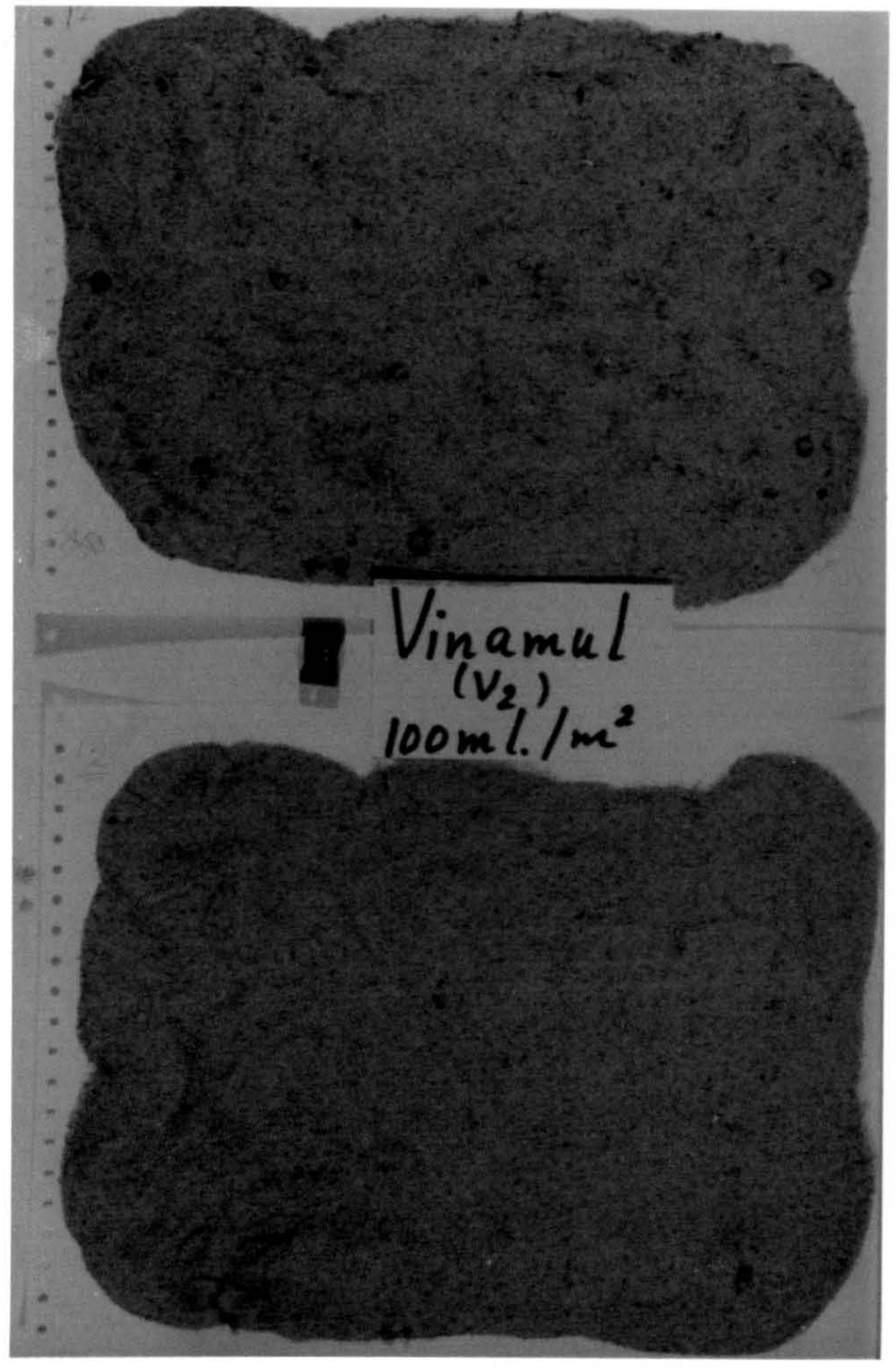
Plates 5.9 & 5.10: Air-Dry Sand Samples From the Surface Layer of the Eucalyptus Experiment (After 405 Days From Treatment With PEG4 0.2% and 0.4%).



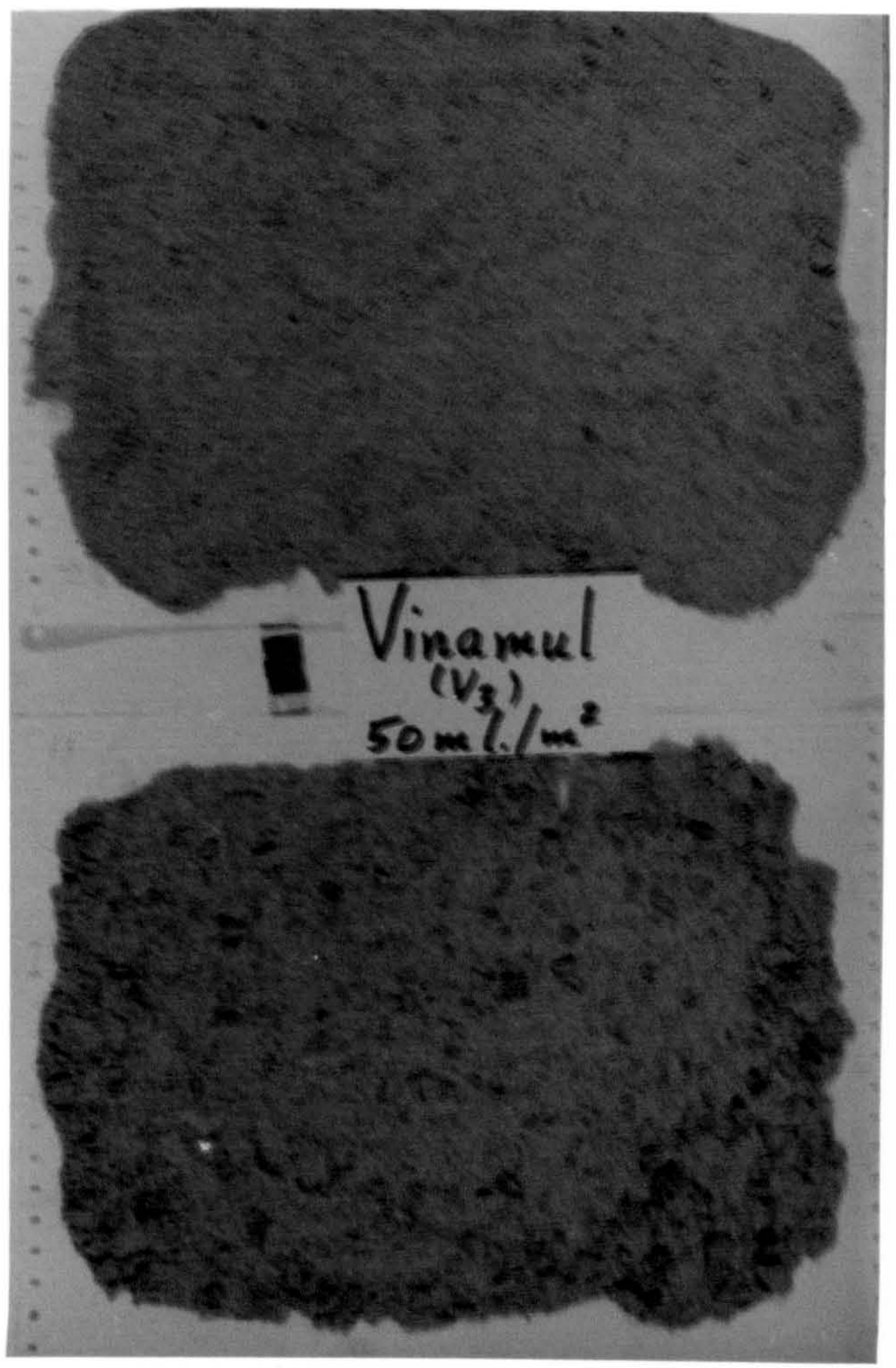


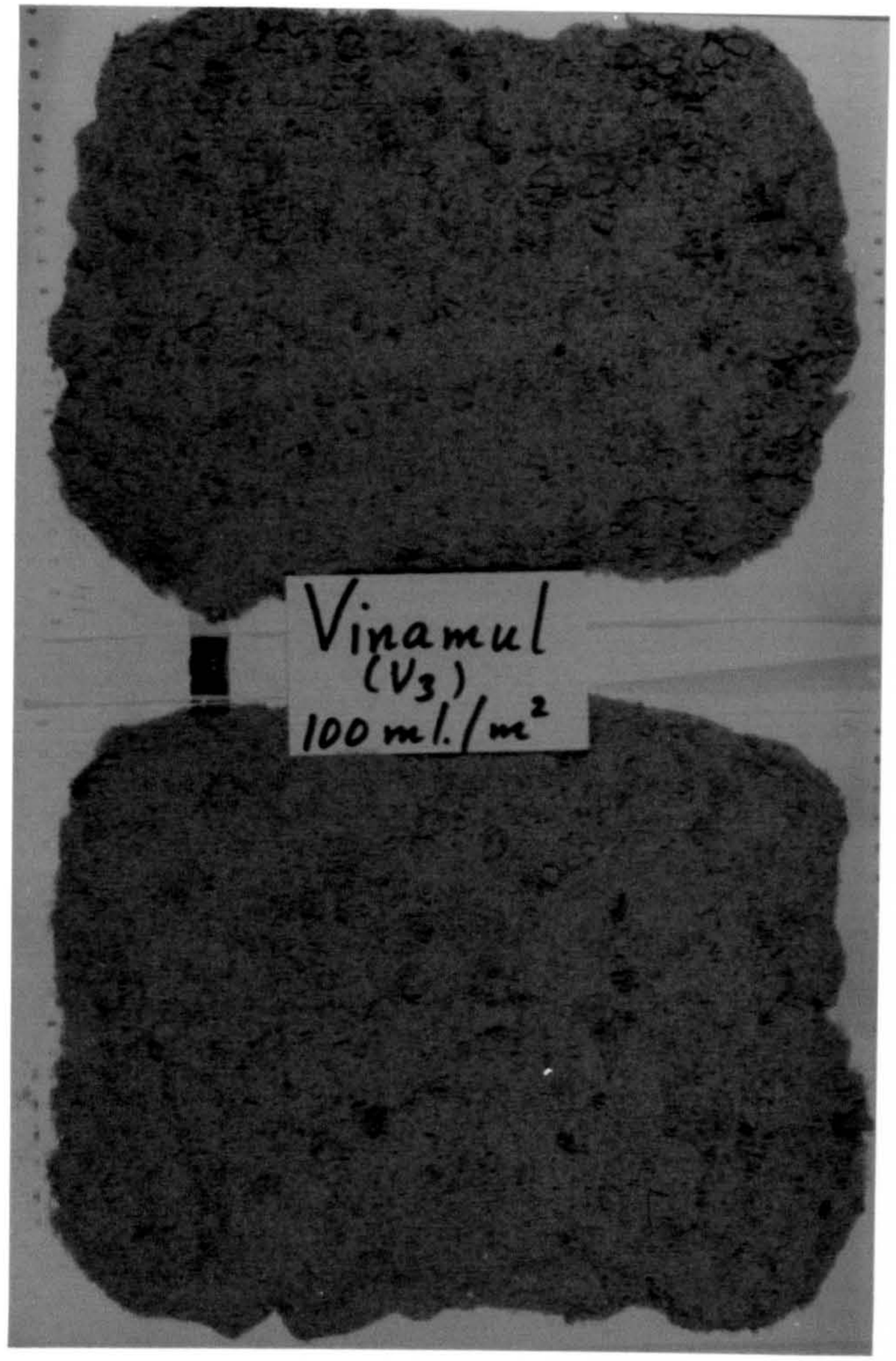
Plates 5.11 & 5.12: Air-Dry Sand Samples From the Surface Layer of the Eucalyptus Experiment (After 405 Days From Treatment With V1 0.05 l $m^{-2}$and 0.10 l m^{-2}).



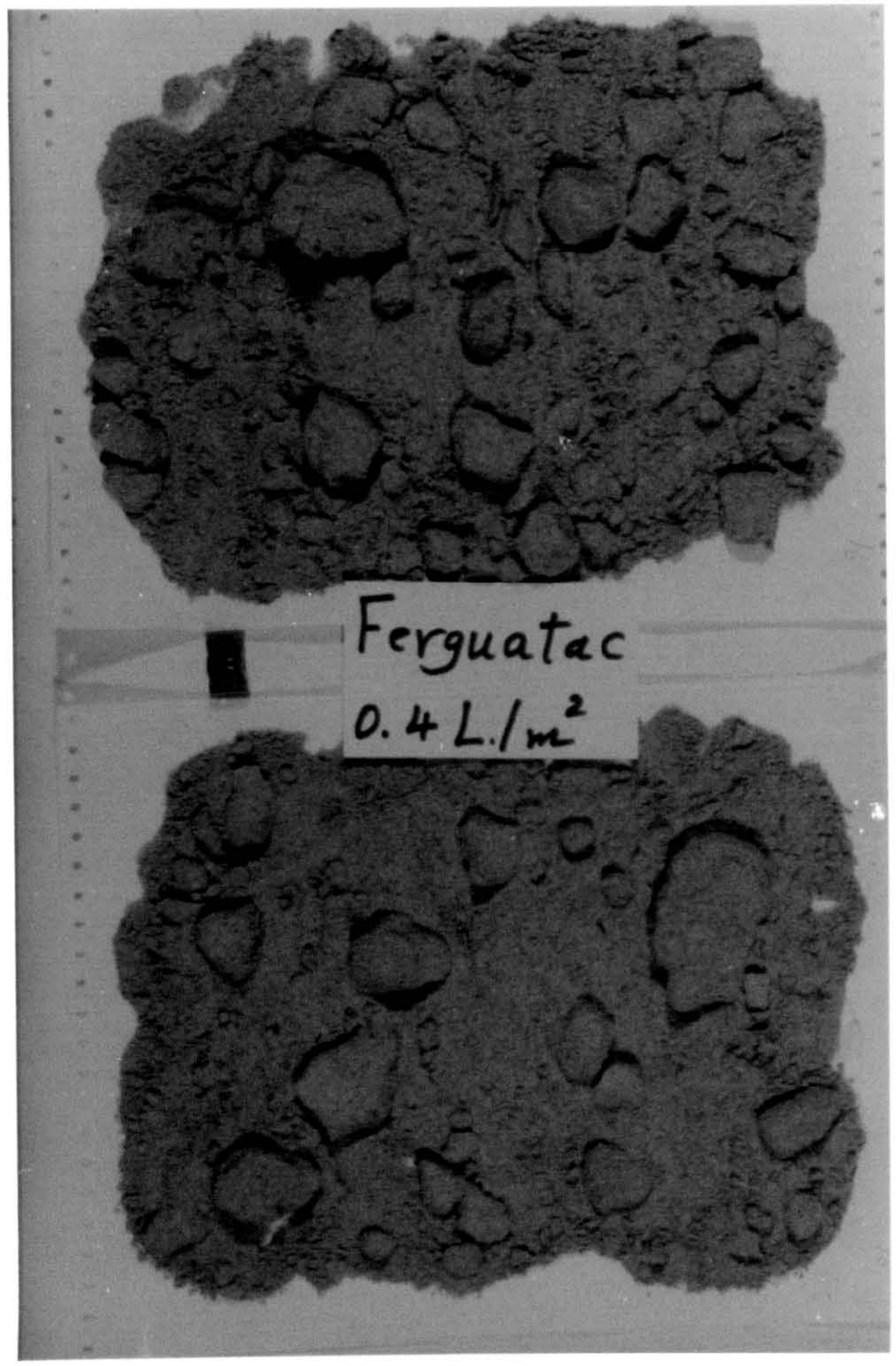


Plates 5.13 & 5.14: Air-Dry Sand Samples From the Surface Layer of the Eucalyptus Experiment (After 405 Days From Treatment With V2 0.05 l $m^{-2}$and 0.10 l m^{-2}).



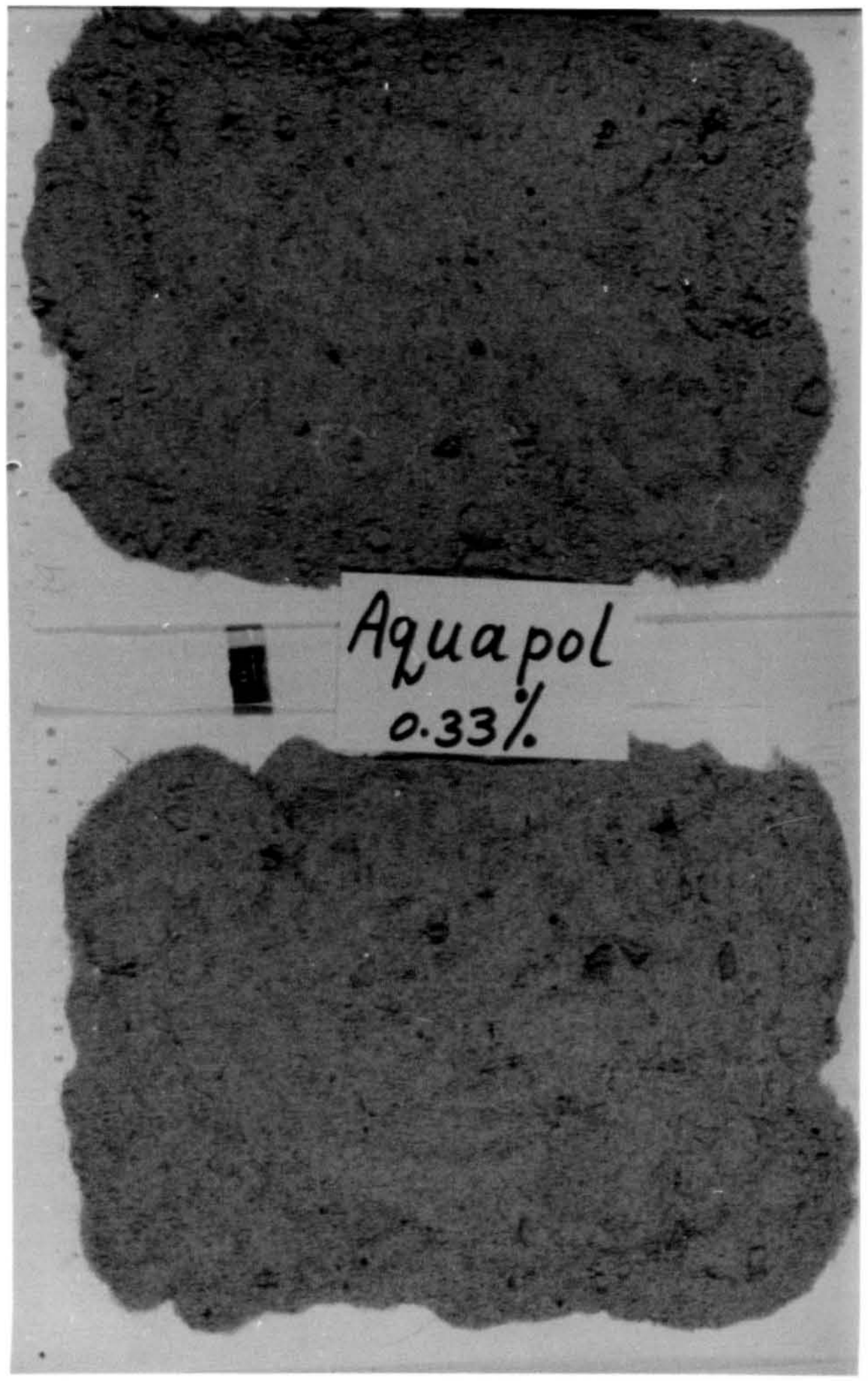


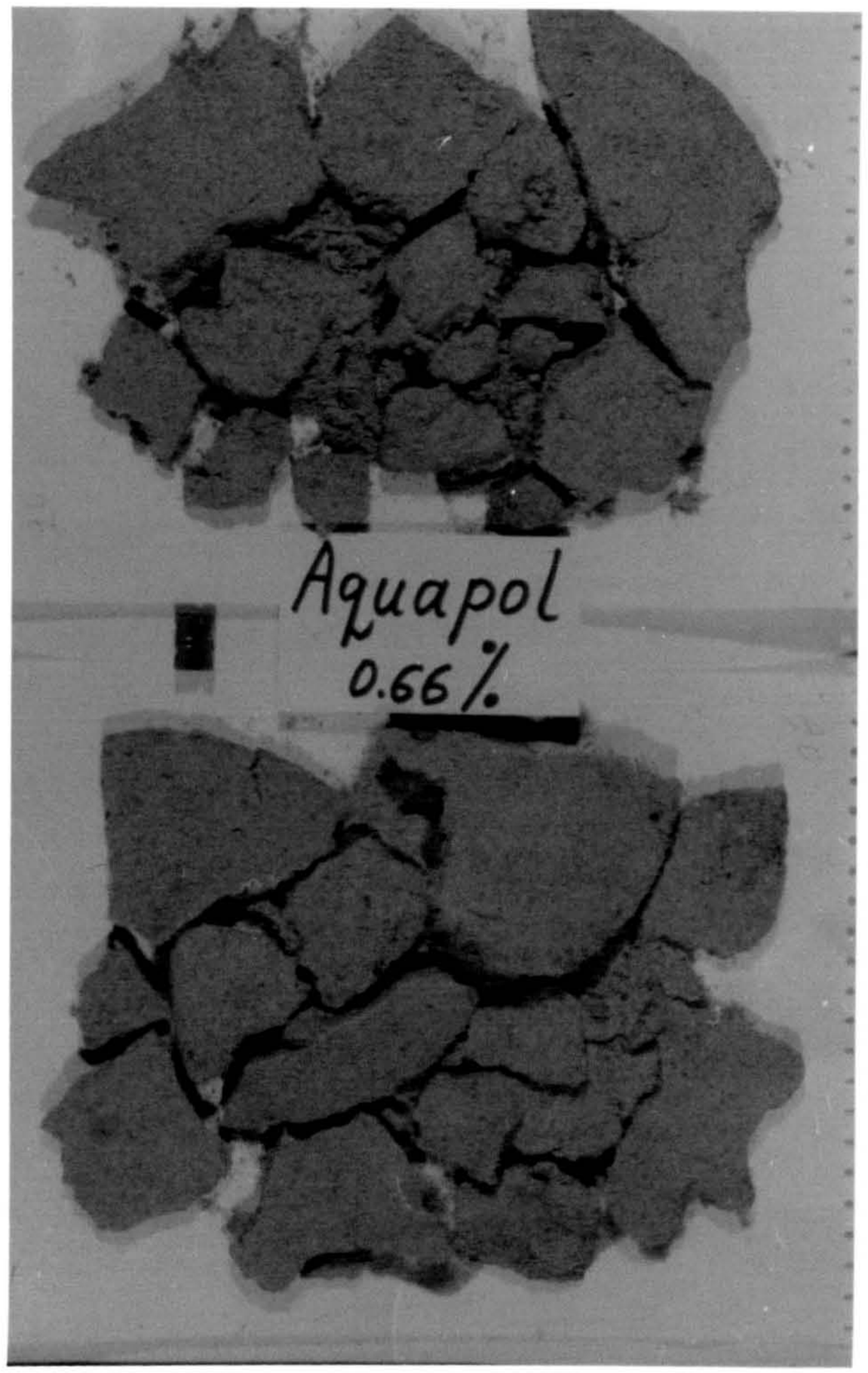
Plates 5.15 & 5.16: Air-Dry Sand Samples From the Surface Layer of the Eucalyptus Experiment (After 405 Days From Treatment With V3 0.05 l $m^{-2}$and 0.10 l m^{-2}).



Plates 5.17 & 5.18: Air-Dry Sand Samples From the Surface Layer of the Eucalyptus Experiment (After 405 Days From Treatment With F.E. 0.2 l $m^{-2}$and 0.4 l m^{-2}).

Plates 5.19 & 5.20: Air-Dry Sand Samples From the Surface Layer of the Eucalyptus Experiment (After 405 Days From Treatment With B.E. 0.5 l $m^{-2}$and 1.0 l m^{-2}).





Plates 5.21 & 5.22: Air-Dry Sand Samples From the Surface Layer of the Eucalyptus Experiment (After 405 Days From Treatment With Aq1 0.33% and 0.66%).

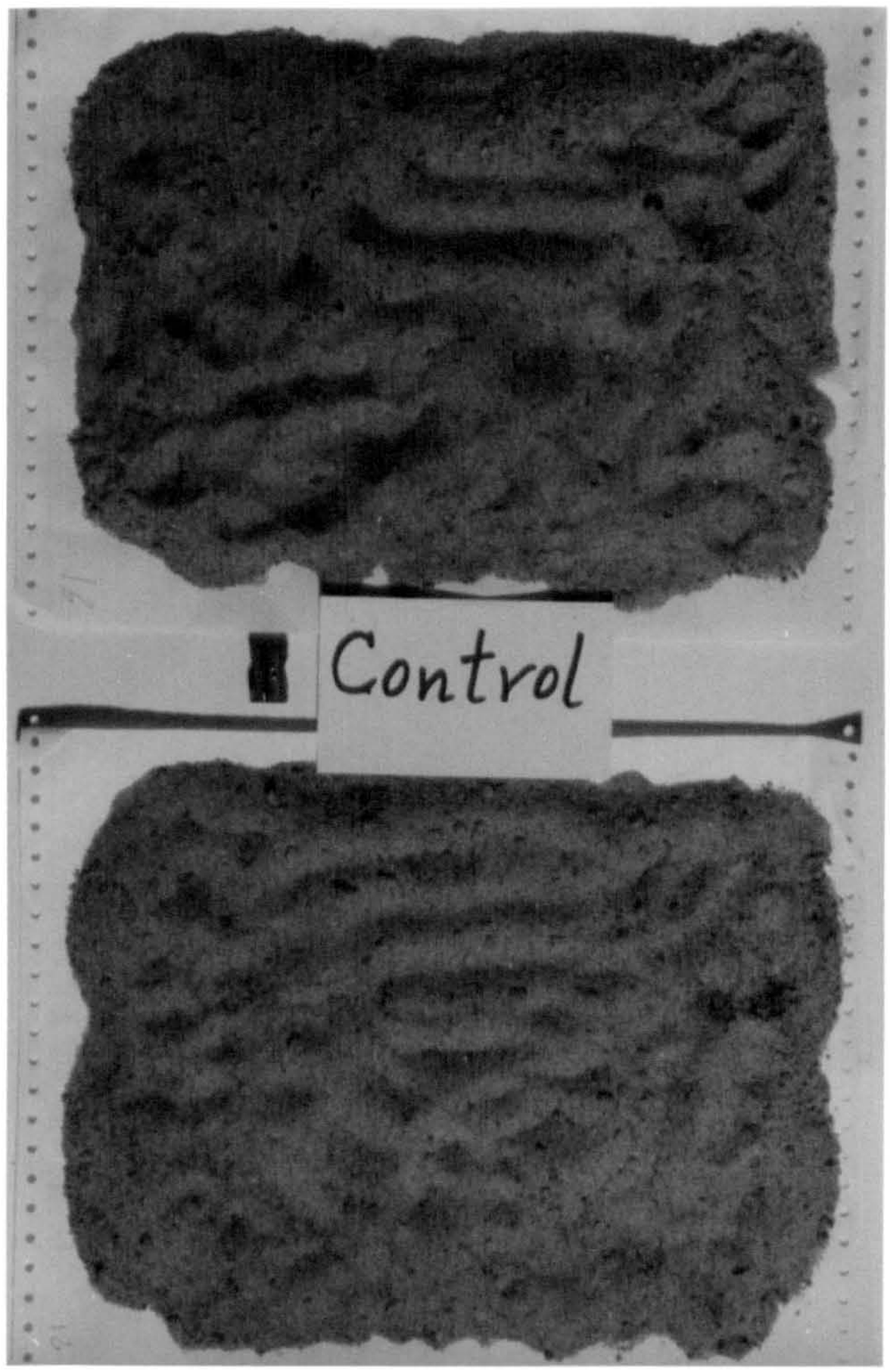


Plate 5.23: Untreated Air-Dry Sand Samples From the Surface Layer of the Eucalyptus Experiment (After 405 Days From Starting).

(both 3 day and 405 day treatments). Water aggregate stability index values (SI) are only for the sand aggregates > 0.5 mm in diameter.

From the figures 5.48 and 5.49 and table 5.39 for the 3 day samples, it is obvious that all the chemical treatments increased the mean weight-diameter of both air-dry and water stable aggregates. The increments were increased with the

FIG. 5.48: EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE MEAN WEIGHT DIAMETER OF AIR-DRY AGGREGATES IN DRURIDGE BAY SAND (3 DAYS AFTER TREATMENT SAND SAMPLES).

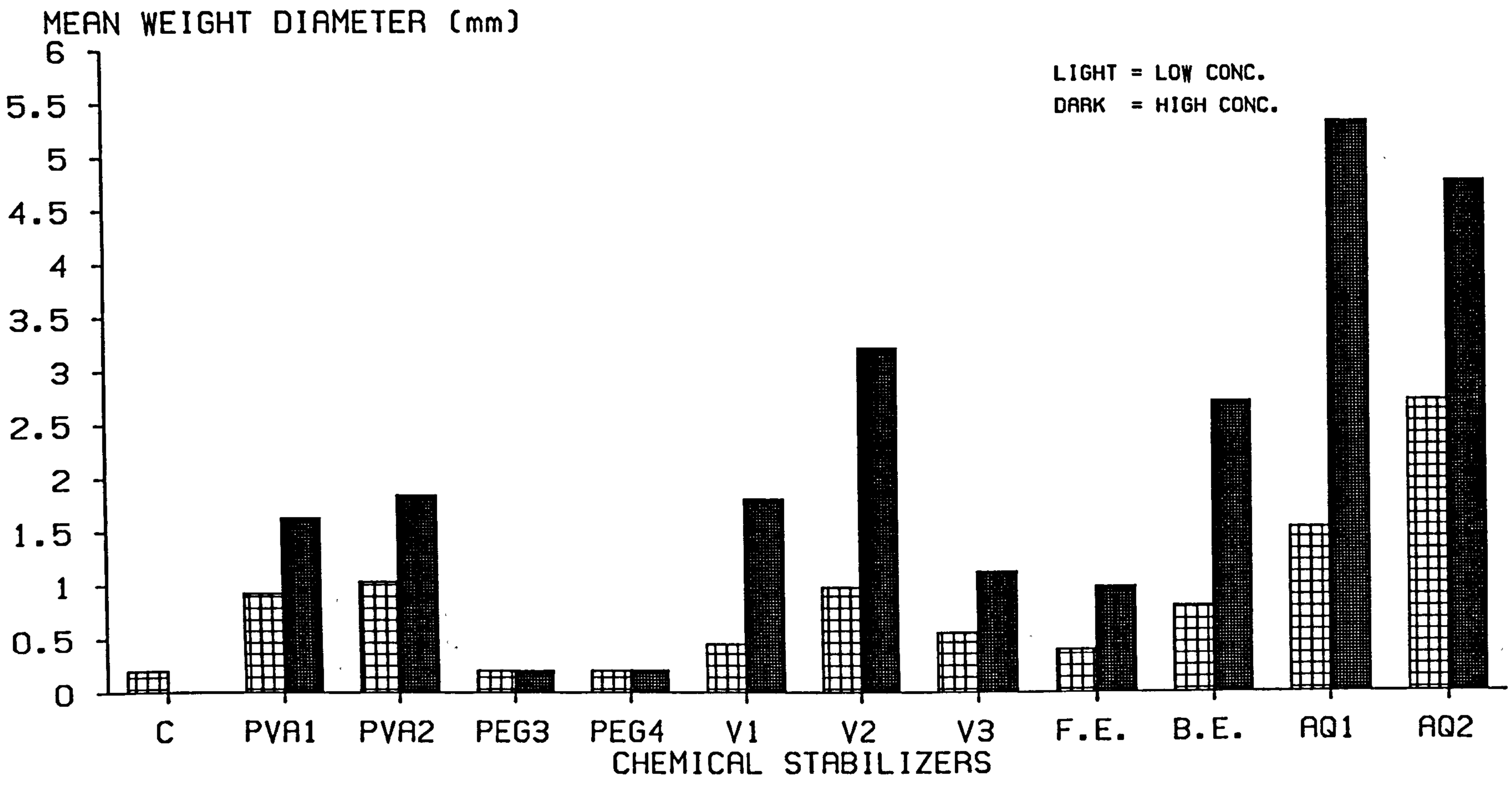


FIG. 5.49: EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE MEAN WEIGHT DIAMETER OF WATER STABLE AGGREGATES IN DRURIDGE BAY SAND (3 DAYS AFTER TREATMENT SAND SAMPLES).

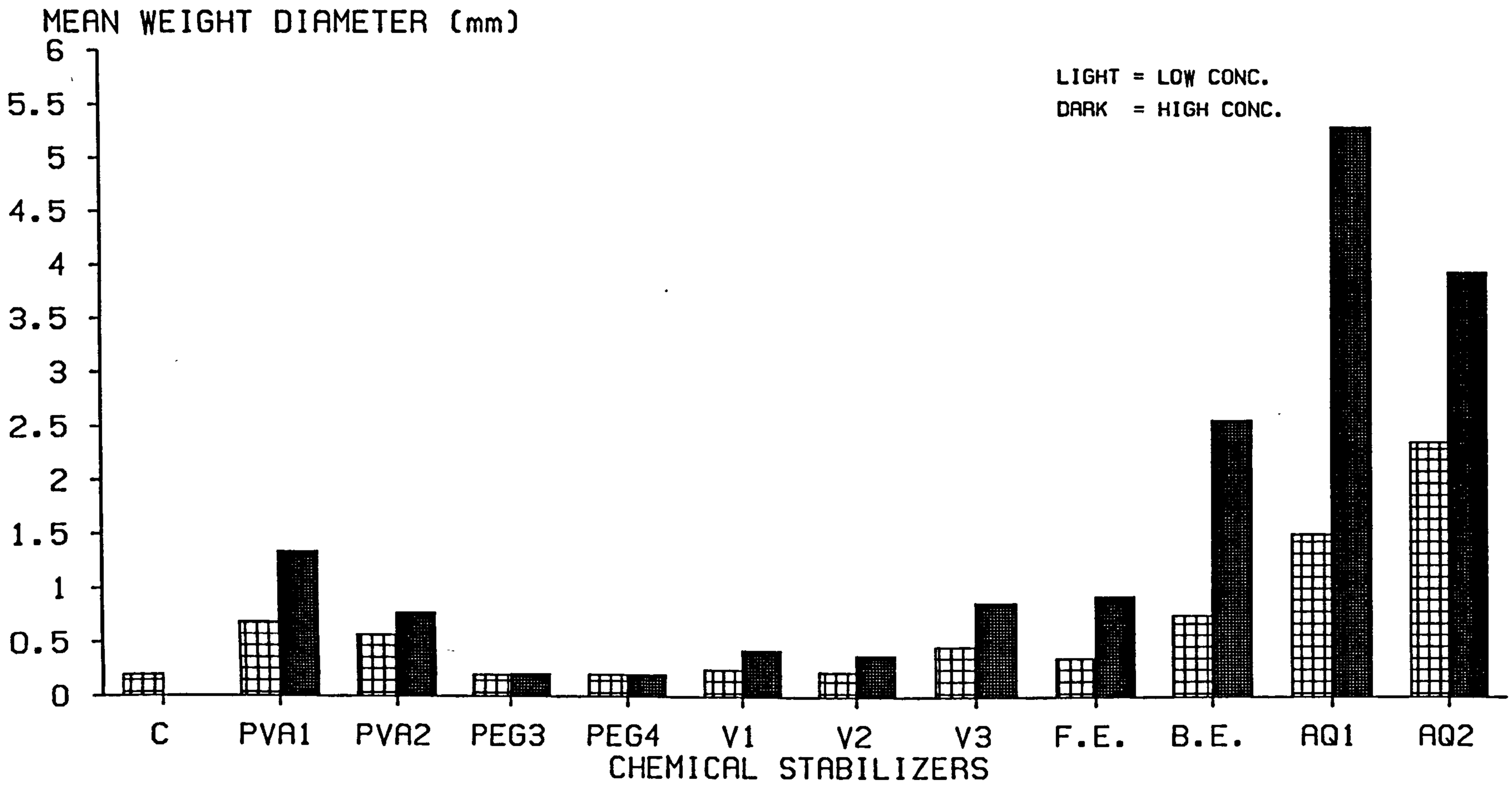


FIG. 5.50: EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE MEAN WEIGHT DIAMETER OF AIR-DRY AGGREGATES IN DRURIDGE BAY SAND (405 DAYS AFTER TREATMENT SAND SAMPLES).

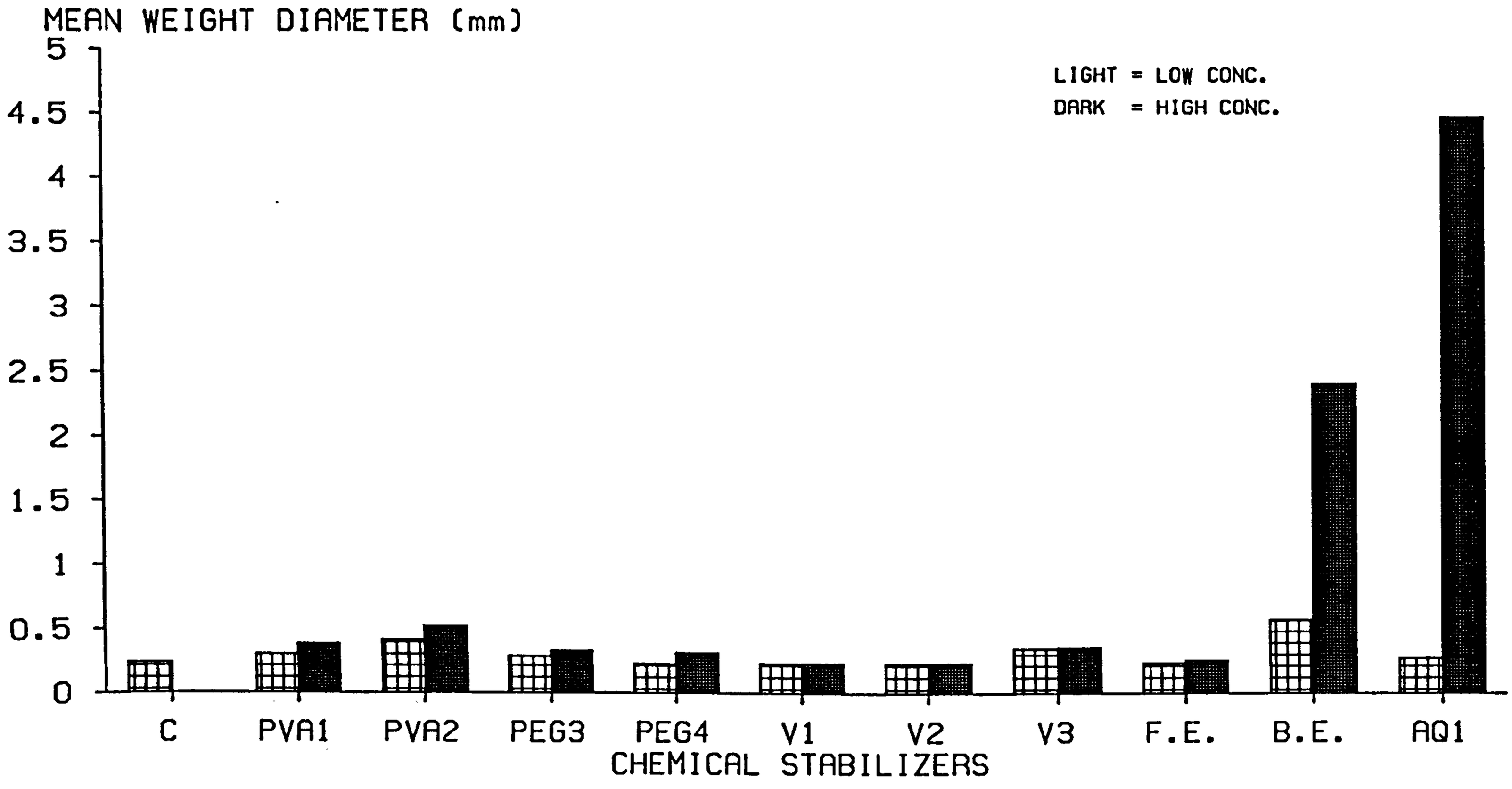


FIG. 5.51: EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE MEAN WEIGHT DIAMETER OF WATER STABLE AGGREGATES IN DRURIDGE BAY SAND (405 DAYS AFTER TREATMENT SAND SAMPLES).

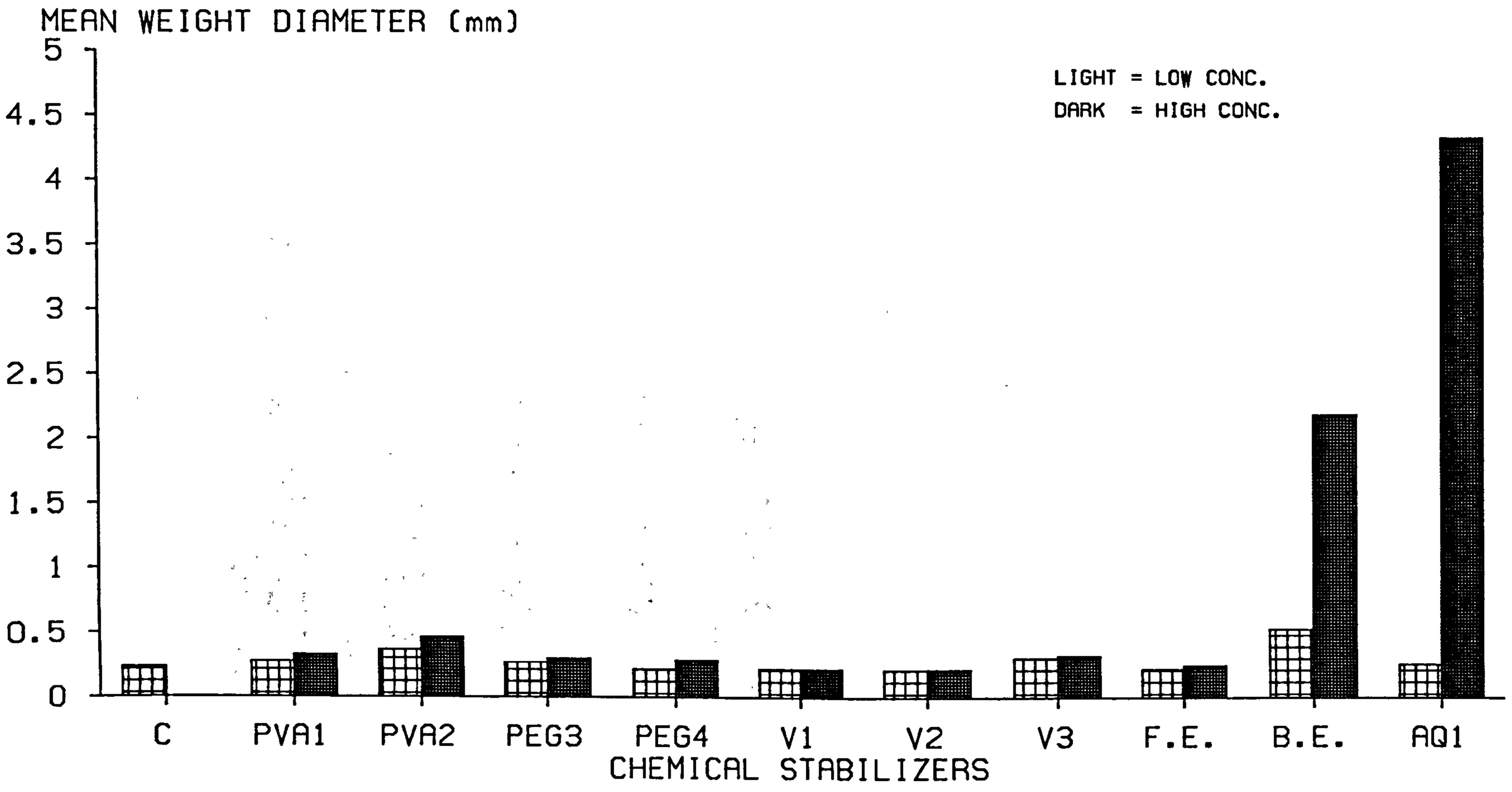


FIG. 5.52: EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE STABILITY INDEX OF WATER STABLE AGGREGATES IN DRURIDGE BAY SAND (3 DAYS AFTER TREATMENT SAND SAMPLES).

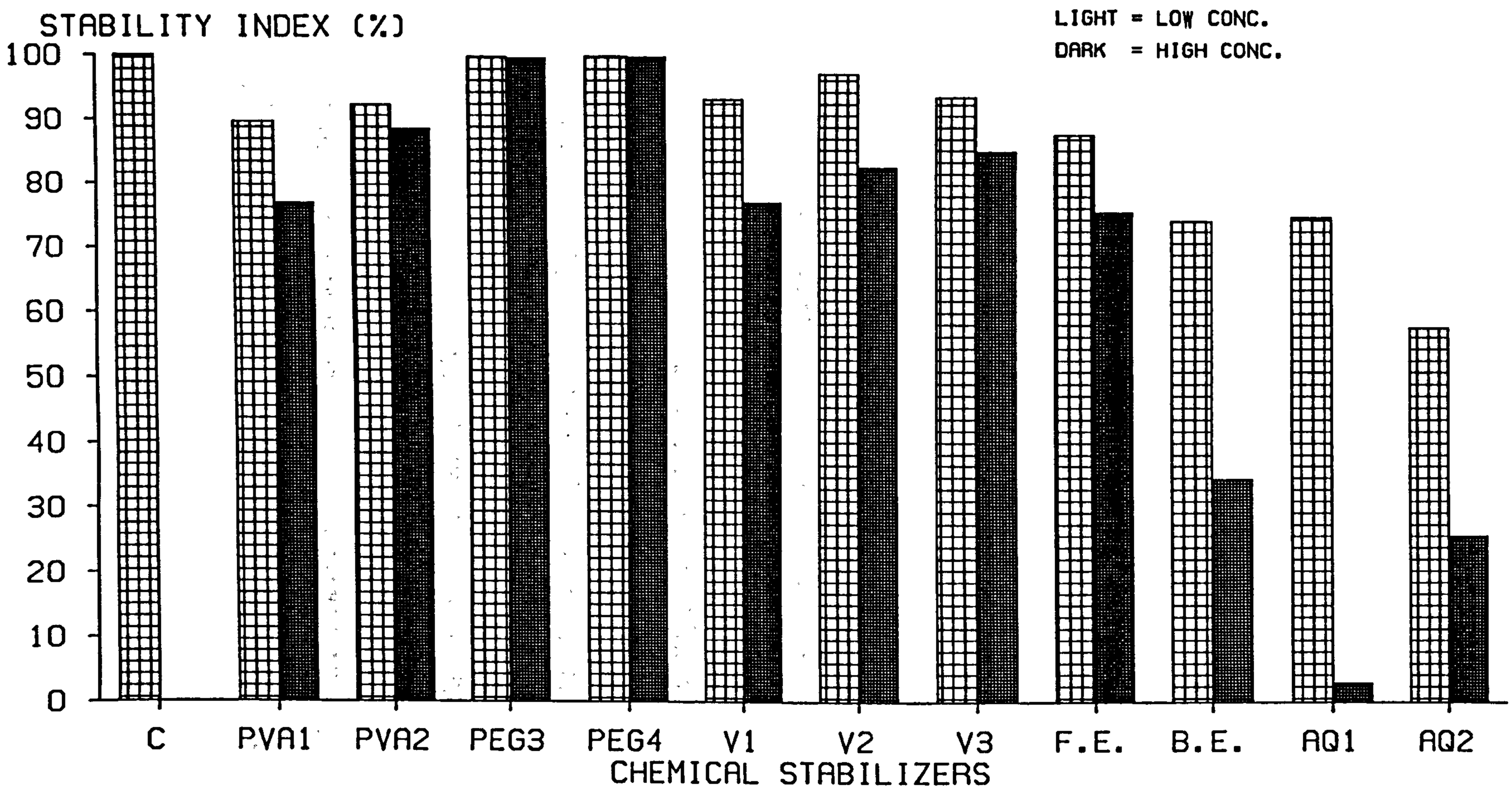


FIG. 5.53: EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE STABILITY INDEX OF WATER STABLE AGGREGATES IN DRURIDGE BAY SAND (405 DAYS AFTER TREATMENT SAND SAMPLES).

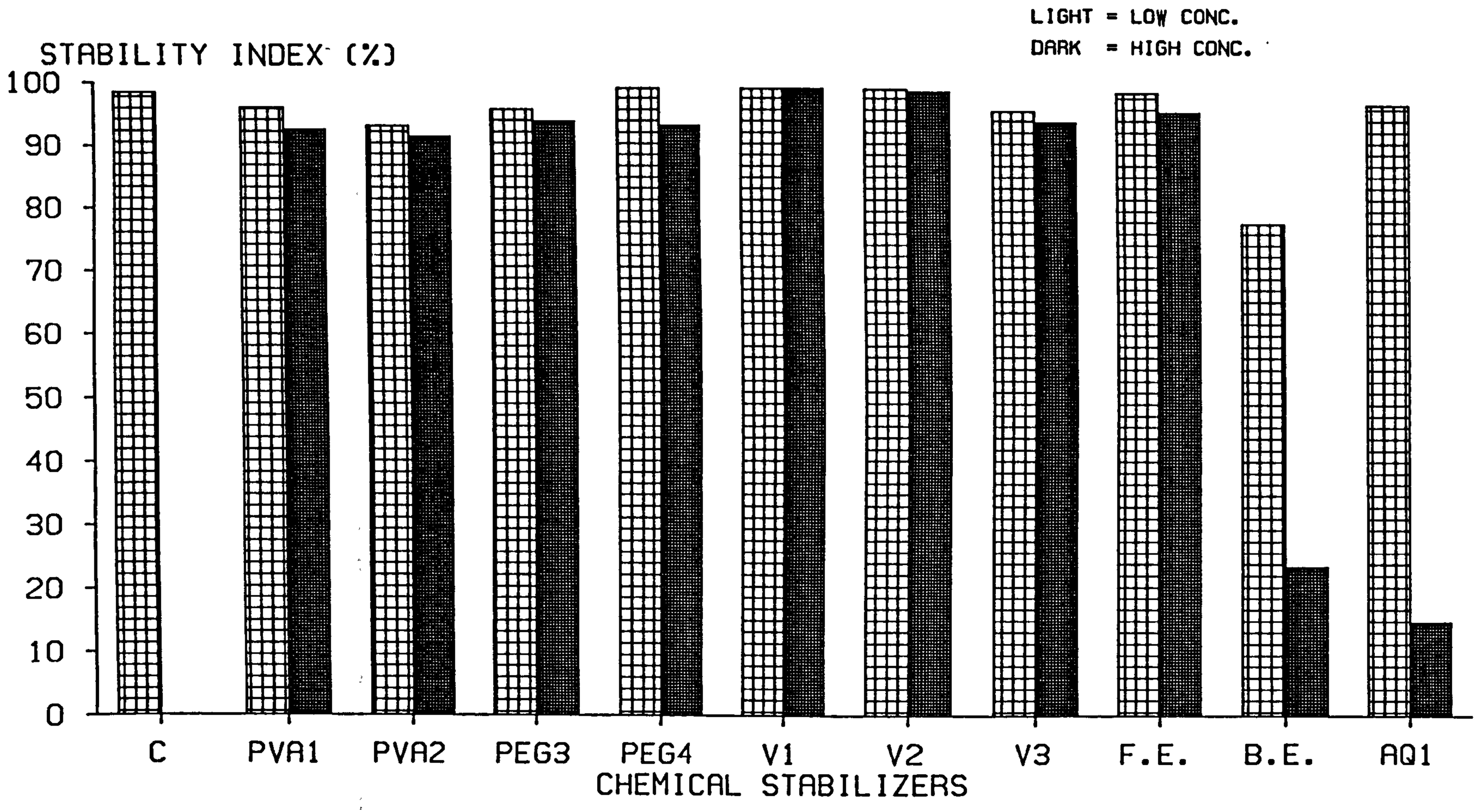


Table 5.39: Mean Weight Diameter (MWD) of Air-Dry and Water Stable Aggregates and the Aggregates Stability Index (SI) in Druridge Bay Sand as Affected by Soil Chemical Stabilizers (3 Days After Treatment Samples).

Treats	Conc.*	Mean Weight Diameter (mm)		Stability Index (SI) (%)
		Air-Dry Aggregates	Water Stable Aggregates	
PVA1	0.2%	0.929	0.688	89.66
	0.4%	1.631	1.340	76.89
PVA2	0.2%	1.040	0.566	92.28
	0.4%	1.843	0.775	88.53
PEG3	0.2%	0.204	0.195	99.68
	0.4%	0.205	0.203	99.51
PEG4	0.2%	0.204	0.201	99.77
	0.4%	0.208	0.201	99.65
V1	0.05 l m^{-2}	0.453	0.246	93.07
	0.10 l m^{-2}	1.804	0.429	76.87
V2	0.05 l m^{-2}	0.981	0.226	96.99
	0.10 l m^{-2}	3.216	0.385	82.51
V3	0.05 l m^{-2}	0.557	0.464	93.43
	0.10 l m^{-2}	1.127	0.871	85.01
F.E.	0.2 l m^{-2}	0.401	0.359	87.67
	0.4 l m^{-2}	0.984	0.931	75.61
B.E.	0.5 l m^{-2}	0.803	0.756	74.16
	1.0 l m^{-2}	2.709	2.566	34.64
Aq1	0.33%	1.528	1.505	74.78
	0.66%	5.320	5.292	2.99
Aq2	200 gm m^{-2}	2.715	2.362	57.78
	250 gm m^{-2}	4.759	3.942	25.76
Control		0.198	0.193	100.00

* All (%) are on the base of air-dry sand.

Table 5.40: Mean Weight Diameter (MWD) of Air-Dry and Water Stable Aggregates and the Aggregates Stability Index (SI) in Druridge Bay Sand as Affected by Soil Chemical Stabilizers (405 Days After Treatment Samples).

Treats	Conc.*	Mean Weight Diameter (mm)		Stability Index (SI) (%)
		Air-Dry Aggregates	Water Stable Aggregates	
PVA1	0.2%	0.302	0.273	96.16
	0.4%	0.381	0.327	92.66
PVA2	0.2%	0.409	0.363	93.26
	0.4%	0.519	0.459	91.59
PEG3	0.2%	0.286	0.265	95.95
	0.4%	0.328	0.296	94.02
PEG4	0.2%	0.224	0.214	99.34
	0.4%	0.313	0.285	93.49
V1	0.05 l m^{-2}	0.225	0.216	99.27
	0.10 l m^{-2}	0.228	0.215	99.35
V2	0.05 l m^{-2}	0.227	0.209	99.19
	0.10 l m^{-2}	0.229	0.213	98.84
V3	0.05 l m^{-2}	0.345	0.303	95.71
	0.10 l m^{-2}	0.356	0.323	93.94
F.E.	0.2 l m^{-2}	0.233	0.216	98.65
	0.4 l m^{-2}	0.256	0.243	95.51
B.E.	0.5 l m^{-2}	0.572	0.530	77.78
	1.0 l m^{-2}	2.408	2.191	23.57
Aq1	0.33%	0.273	0.253	96.75
	0.66%	4.468	4.331	14.82
Control		0.236	0.229	98.48

* All (%) are on the base of air-dry sand.

increase in the chemical concentrations. This result is in agreement with Szczypa et al., 1976; Tayel and El-Hady, 1981b; and Al- Debagi, 1983. The chemicals can be ranked as follows in relation to the dry mean weight-diameter:

Aq1 0.66% (5.320 mm) > Aq2 250 gm m^{-2} (4.759 mm) > V2 0.10 l m^{-2} (3.216 mm) > Aq2 200 gm m^{-2} (2.715 mm) > B.E. 1.0 l m^{-2} (2.709 mm) > PVA2 0.4% (1.843 mm) > V1 0.10 l m^{-2} (1.804 mm) > PVA1 0.4% (1.631 mm) > Aq1 0.33% (1.528 mm) > PVA2 0.2% (1.040 mm) > F.E. 0.4 l m^{-2} (0.984 mm) > the remaining chemical treatments (0.981 - 0.204 mm) > control (0.198 mm).

The increases in the water stable mean weight diameter can be ranked as follows:

Aq1 0.66% (5.292 mm) > Aq2 250 gm m-2 (3.942 mm) > B.E. 1.0 l m^{-2} (2.566 mm) > Aq2 200 gm m^{-2} (2.362 mm) > Aq1 0.33% (1.505 mm) > PVA1 0.4% (1.340 mm) > F.E. 0.4 l m^{-2} (0.931 mm) > the remaining chemical treatments (0.871 - 0.195 mm) > control (0.193 mm).

Only Aq1 (0.66% and 0.33%), Aq2 (250 and 200 gm m^{-2}), and B.E. (1.0 and 0.5 l m^{-2}) followed by PVA1 0.4% were resistant to water disruption in the wet aggregation test.

The mean weight-diameter data for both wet and dry aggregate stability for the 405 day experiment is shown in table 5.40. Figures 5.50 and 5.51 show that samples treated with Aq1 0.66% and B.E. 1.0 l m^{-2} showed an extremely high mean weight-diameter of both air-dry and water stable aggregates when compared with the remaining chemical treatments. The mean weight-diameter for the B.E. 0.5 l m^{-2} and for the PVA2 0.4% treatments were at least twice as large as for the control. The effect of the chemical treatments on both mean weight-diameter parameters, can be ranked in the following order:

Aq1 0.66% > B.E. 1.0 l m^{-2} > B.E. 0.5 l m^{-2} > PVA2 0.4% > PVA1 0.2% > the remaining chemical treatments and the control.

The effect of the chemical stabilizers on the stability index of water stable

aggregates is summarized in figures 5.52 and 5.53 and tables 5.39 and 5.40. Sand aggregates > 0.5 mm in diameter were the only aggregates treated as real, since about 99.4% of the individual sand particles sizes were smaller than 0.5 mm in diameter. As the stability index is in fact the change between the air-dry aggregates and the water stable aggregates, the smaller the change, the more water stable the aggregates are (De Leenheer and De Boodt, 1967; Hartmann et al., 1975; and Tayel and El-Hady, 1981b).

From figure 5.52 and table 5.39 for the 3 day experiment, it is clear that Druridge Bay sand is naturally structureless, as the stability index of the control treatment was 100%. This is due to the lack of both organic matter (< 1%) and clay (< 1%). Although all the chemical treatments reduced the stability index, the reduction was exceptionally high with Aq1 0.66%. The stability index of water stable aggregates under the effect of various chemical treatments can thus be ranked as follows:

Aq1 0.66% (2.99%) < Aq2 250 gm m^{-2} (25.76%) < B.E. 1.0 l m^{-2} (34.64%) < Aq2 200 gm m^{-2} (57.78%) < B.E. 0.5 l m^{-2} (74.16% < Aq1 0.33% (74.78%) < F.E. 0.4 l m^{-2} (75.61%) < V1 0.10 l m^{-2} (76.87%) < PVA1 0.4% (76.89%) < rest of the chemical treatments (82.51% - 99.77%) < control (100%).

In the long term 405 day experiment, the results in figure 5.53 and table 5.40 show an extremely high reduction in the stability index of water stable aggregates caused by Aq1 0.66% followed by B.E. 1.0 l m^{-2} and B.E. 0.5 l m^{-2}. All other chemical treatments lost their effectiveness to withstand water disruption (though see earlier comments about F.E.). The long term stability index of the water stable aggregates can therefore be arranged as follows: Aq1 0.66% (14.82%) < B.E. 1.0 l m^{-2} (23.57%) < B.E. 0.5 l m^{-2} (77.78%) < the remaining chemical treatments and the control (91.59% - 99.35%).

In both the 3 days and 405 days experiments where the aggregates remained water stable, the stability index decreased as the concentration of stabilizer chem-

icals increased.

The effect of growing Eucalyptus in the untreated sand (control) can be seen to be beneficial as there has been a slight reduction in the stability index of the control from the 3 day to 405 day experiments.

In conclusions, the folllowing points could be summarised:-

1. It is obvious that the untreated Druridge sand is structureless. The stability index (SI) of the control in the uncultivated sand was 100%.
2. Cultivation of sand with Eucalyptus for a period of 405 days increased the formation of sand aggregates > 0.5 mm in both the dry and wet aggregation tests of the control. This was probably due to the increase in both microbial activity and the organic matter derived from the decomposition of leaf litter and roots.
3. In the 3 day samples, all chemical treatments increased the mean weight-diameters of both air-dry and water stable aggregates in proportion to the concentrations applied. Only Aq1 (0.66% and 0.33%), Aq2 (250 and 200 gm m^{-2}) and B.E. (1.0 and 0.5 l m^{-2}) followed by PVA1 0.4% effectively withstood water disruption in the wet aggregation test.
4. In the samples from the 405 day experiment, Aq1 0.66% followed by B.E. 1.0 l m^{-2} showed an extremely high mean-weight-diameters of both air-dry and water stable aggregates when compared with the remaining chemical treatments.
5. Although the F.E. (0.4 and 0.2 l m^{-2}) treatments did not give any good results in either the air-dry or water stable aggregation tests. In the greenhouse both F.E. concentrations appeared to maintain a much more effective stable surface cover when compared to all other treatments except Aq1 0.66% and B.E. (1.0 and 0.5 l m^{-2}). This suggests that aggregate stability tests might not always give an absolute measure of the long term stabilizing ability of some chemical treatments.

6. The wetting process caused considerable disruption of the previously dry aggregates with all chemical treatments, except Aq1 0.66%, Aq2 (250 and 200 gm m^{-2}), and B.E. (1.0 and 0.5 l m^{-2}).
7. A statistical analysis of sand aggregates percentages > 0.5 mm in diameter, indicated high significant differences (at 1% level of significance) between various chemical treatments (appendix tables 5.13 - 5.16). In this respect, the calculated F-values were much higher than the table F-values in both 3 day and 405 day experiments, and for both air-dry and water stable aggregation tests. Aq1 0.66% gave the highest individual 95% confidence interval (CI)* for the mean based on pooled standard deviation in all cases.
8. Of all the chemicals tested, Aq1 0.66% appears to be the most effective stabilizing agent, since it gave the highest aggregation percentages of both air-dry and water stable sand aggregates, the highest mean weight-diameter, and the lowest stability index, in comparison with the rest series of chemical treatments in both the 3 day and 405 day experiments.

   B.E. 1.0 l m^{-2} followed by B.E. 0.5 l m^{-2} are also effective in stabilizing aeolian sand dunes as they gave good sand aggregation percentages. Although not as successful as Aq1, being a by-product of the petroleum industry, bi-

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* *Each confidence interval is calculated by the formula:-*

$$\bar{x_i} - ts_p/\sqrt{n_i} \quad to \quad \bar{x_i} + ts_p/\sqrt{n_i}$$

Here $\bar{x_i}$ and n_i are the sample mean and sample size for level i, s_p = POOLED STDEV = $\sqrt{MSERROR}$ is the pooled estimate of the common standard deviation, σ, and t is the value from a t-table corresponding to 95% confidence and the degrees of freedom associated with MS ERROR (Ryan et al., 1985 page 197). These intervals give us some idea of how the population means differ.

tumen may be more economically attractive particularly in oil producing countries.

Although Aq2 (250 and 200 gm m^{-2}) gave better short term aggregation results than B.E. (1.0 and 0.5 l m^{-2}), both concentrations need further assessment in relation to their long term effectiveness.

9. All the other chemical treatments: PVA1 (0.2% and 0.4%); PVA2 (0.2% and 0.4%); PEG3 (0.2% and 0.4%); PEG4 (0.2% and 0.4%); V1 (0.05 and 0.10 l m^{-2}); V2 (0.05 and 0.10 l m^{-2}) and V3 (0.05 and 0.10 l m^{-2}), are not very useful sand dune stabilizers, as they all lost their stabilization characteristics in the first 3 months of the greenhouse experiments. **This is contrary to the findings of much of the literature (see section 5.1.5.1).** They could however, be used as general soil conditioners.

5.2 Effect of Soil Chemical Stabilizers on Seed Germination and Plant Growth

5.2.1 Introduction

Most of the research conducted into the use of soil conditioners has been focused on a need to either improve soil physical characters, or to increase the surface stability against wind and water erosion. Only recently has attention been paid to the effect of these products on seed germination and plant growth. For example, De Boodt (1979) listed 85 trials had been carried out in Belgium during 1977 and 1978 on the effect of different soil conditioners on rates of germination of various crops, including, chicory (53 trials), carrots (9 trials), sugar beet (6 trials), mangols (6 trials), salsify (5 trials), endive (3 trials) and spinach (3 trials). In 85% of these trials, germination on the treated plots was greater than that on the untreated ones.

Since vegetation growth is the most effective way of ensuring long term sand dune stabilization, investigations into chemical-vegetation interaction are essential, in order to determine which stabilizers can support vegetation growth (Owusu et al., 1985).

In this study, two greenhouse experiments were conducted: (i) germination of seeds in chemically treated dune sand; and (ii) applying the stabilizers after planting Eucalyptus, Acacia and marram grass into pots of sand.

The objectives of these two experiments were: first, to study, the effect of the stabilizers under investigation on the emergence and growth of seeds of marram grass, rye grass (*Merlinda and Melion spp.*) and *Panicum spp.*; second, to study, the effect of the chemical treatments on the growth of *Eucalyptus microtheca*, *Acacia cyanophylla* plants and marram grass tillers in Druridge Bay dune sand.

5.2.2 Effect of the Selected Chemical Stabilizers on Seed Germination

5.2.2.1 Theoretical Basis

Applications of soil chemical stabilizers to the soil surface could inhibit seed germination, due either to directly toxic effects on the plants, or indirectly by adversly changing the chemical and physical characteristics of soils. Alternatively the reverse could happen and seed germination could be enhanced by resuming nutrient status and/or enhancing the physical properties of the soil.

Rather high amounts of polyacrylamid (PAM); polyacrylonitrile (PAN); vinylacetate maliec acid (VAMA) and some other polymers that produced good structure (no more than 0.8% to 1.0% on air-dry soils weight) inhibited some pure cultures and groups of micro-organisms, germination of plants and their roots and stem development for the first 3 to 5 days, but thereafter the crops on the treated soil equaled and then exceeded the control in these respects (Kachinskiy et al., 1967). Armbrust and Dickerson (1971) found that bituminous emulsion reduced the emergence of tomato seeds, and PVA, carboxylated styrene butadiene latex, and bituminous emulsion reduced the emergence of bean seeds.

Tayel et al., (1981) found that both bituminous emulsion and PVAc delayed the germination of barley plant seeds (*Hordium vulgares L.*) in sandy and sandy loam soils, but improved germination rates in a calcareous soil. PAM enhanced germination process at all concentrations used in the three soils.

In many studies, the increase in seed germination was due to the reduction of soils surface crust formation (Anter and Hillel, 1972; Gabriels et al., 1975a; Oades, 1976; De Boodt, 1978; and Tayel et al., 1981).

Stefanson (1974) found that the application of 0.005% of PVA to the surface of a red-brown soil was very effective in reducing surface crust formation, improving soil structure and increasing the percentage of wheat seeds emergence from 20% in the untreated soil to 90% in the treated one.

Bennett et al (1964) found that seedling emergence of cotton was increased to 69.2% in a fine sandy loam soil treated with 0.5% asphalt emulsion when compared with 10.8% seedling emergence in the untreated soil.

In a silty clay loam soil, the beneficial effect of petroleum mulch compared with untreated soil, on germination and seedling growth was attributed to the improvement of soil water conditions and soil temperature conditions under the mulch (Kowsar et al., 1969).

Different concentrations of PAM including 4% solution at the rate of 5000 l h^{-1}, and 20 gm $m^{-2}$was found to increase the germination percent of sugar beet seeds (De Boodt and Gabriels, 1973; and De Vleeschauwer and Gabriels, 1976).

In a sand culture experiment, in which the sand was treated with the soil conditioners PVAc; PAM and PVA at various concentrations, namely 0.01%; 0.05%; 0.10%; 0.20% and 0.40% of the liquid phase of the sand culture (Anter and De Boodt, 1976). PVAc enhanced the germination of corn seeds followed by PAM. PVA at concentration higher than 0.10% obviously decreased the germination; while the concentrations < 0.10% had little effect.

Having established that all the chemicals treatments allowed infiltration to occur, an experiment was designed to test the effect of the different concentrations of the various stabilizers on the germination and emergence of marram grass, rye grass (*Merlinda spp.* and *Melion spp.*) and *Panicum spp.* seeds.

5.2.2.2 Materials and Methods

In a greenhouse experiment 25 seeds of each of marram grass and rye grass (*Merlinda spp.* and *Melion spp.*) and 0.1 gm of *Panicum spp.* seeds were sown into pots containing sand from Druridge Bay. Each pot contained 300 gm of air-dry sand which had been irrigated to saturation, covered for two days to allow to drain to field capacity moisture content (22% on air-dry weight). It was at this level of moisture content, that sowing and the application of the chemical

materials was carried out. The test followed a completely randomized design with three replications for each treatment and the control.

During the growing period the moisture content of all samples was maintained by adding 20 ml of water to each pot every two days. Number of germinations per pot were calculated periodically each three days.

As well as number of seeds germinating the 'health' of the seedlings is also important thus after 30 days the seedlings were removed and the oven-dry weight of the shoots and roots was determined as a measure of 'health'.

5.2.2.3 Results, Statistical Analysis and Discussions

a. Effect of the Chemical stabilizers on the Germination Numbers:

Counts of seeds germinating were taken every three days over a period of 3 weeks from sowing. The number of seeds germinating over the three week period are given in tables 5.41 - 5.44, and numbers germinating expressed as a percentage of the total number of seeds planted are shown in figures 5.54 - 5.57.

The results show that the overall germination was effected by both the different stabilizers and their concentrations. Some chemicals enhanced early germination for the seeds, others inhibited them. Furthermore, the response to the stabilizers was not constant for the four different species used. After 9 days Aq1 (0.66%); Aq2 (200 gm m^{-2}); V1 (0.10 l m^{-2}) and V2 (0.10 l m^{-2}) had the highest germination rates of *Panicum spp.* even exceeding the control, the cause of this is unclear but could be higher temperatures (5.1.3) or better moisture characteristics (5.1.2 and 5.1.4). At 21 days however the situation had changed and the control had the highest mean germination rate of 7.1. Of the treated sets Aq1 (0.66%); B.E. (1.0 l m^{-2}) and V1 (0.05 l m^{-2}) had germination rates in excess of 5 seeds. Following these in descending order of germination were:-

V1 (0.10 l m^{-2}); V3 (0.10 l m^{-2}); F.E. (0.4 l m^{-2}) and PEG4 (0.4%) and V2

Table 5.41: Effect of Various Chemical Stabilizers on the Number of *Panicum spp.* Germinations Per Pot.

Treats	Conc.*	Number of Germinations After Days From Cultivation						
		3	6	9	12	15	18	21
PVA1	0.2%	0	0	0	0	3	3	4
		0	0	2	2	4	4	4
		0	0	0	0	1	1	2
PVA1	0.4%	0	0	1	1	2	2	2
		0	0	0	2	4	4	5
		0	0	0	2	3	3	4
PVA2	0.2%	0	0	0	0	1	3	4
		0	0	0	0	0	2	2
		0	0	0	0	3	3	4
PVA2	0.4%	0	0	1	3	4	6	6
		0	0	0	0	0	1	2
		0	0	1	1	1	1	1
PEG3	0.2%	0	0	0	0	2	3	4
		0	0	1	1	4	4	4
		0	0	0	0	2	3	3
PEG3	0.4%	0	0	0	0	0	0	0
		0	0	0	0	0	3	4
		0	0	0	1	1	1	1
PEG4	0.2%	0	0	0	1	2	2	2
		0	0	2	5	5	5	6
		0	0	0	1	1	1	1
PEG4	0.4%	0	0	1	1	2	2	2
		0	0	2	2	2	6	6
		0	0	1	2	4	4	4
V1	0.05 l m^{-2}	0	0	0	2	2	4	4
		0	0	0	2	4	10	10
		0	0	0	0	1	3	3
V1	0.10 l m^{-2}	0	0	3	3	4	5	6
		0	0	2	2	2	4	5
		0	0	2	3	3	3	3
V2	0.05 l m^{-2}	0	0	0	0	1	1	3
		0	0	0	0	0	0	0
		0	0	0	0	4	6	7
V2	0.10 l m^{-2}	0	0	0	1	3	6	6
		0	0	3	3	3	3	3
		0	0	3	3	3	3	3

Continued Table 5.41

Treats	Conc.*	Number of Germinations After Days From Cultivation						
		3	6	9	12	15	18	21
V3	0.05 l m^{-2}	0	0	2	3	3	3	4
		0	0	1	1	1	2	2
		0	0	0	0	1	2	2
V3	0.10 l m^{-2}	0	0	0	1	1	2	2
		0	0	0	1	4	7	8
		0	0	2	2	2	3	3
F.E.	0.2 l m^{-2}	0	0	0	0	0	0	0
		0	0	0	0	0	2	5
		0	0	0	1	1	3	4
F.E.	0.4 l m^{-2}	0	0	0	2	2	2	2
		0	0	0	1	4	6	7
		0	0	0	0	3	3	3
B.E.	0.5 l m^{-2}	0	0	0	0	1	3	3
		0	0	1	1	1	1	1
		0	0	0	0	1	1	1
B.E.	1.0 l m^{-2}	0	0	1	1	4	5	5
		0	0	1	2	7	8	8
		0	0	2	4	6	6	6
Aq1	0.33%	0	0	1	1	2	3	3
		0	0	0	1	1	2	2
		0	0	0	0	1	1	2
Aq1	0.66%	0	0	0	1	1	2	3
		0	0	9	9	13	14	14
		0	0	2	3	3	3	3
Aq2	200 gm m^{-2}	0	1	1	2	2	2	2
		0	1	4	4	4	4	4
		0	2	2	2	2	2	2
Aq2	250 gm m^{-2}	0	0	0	0	0	0	0
		0	0	1	1	1	1	1
		0	0	2	2	2	2	2
Control		0	0	0	1	1	5	7
		0	0	0	1	7	9	9
		0	0	0	1	3	5	6

* All (%) are on the base of air-dry sand.

Table 5.42: Effect of Various Chemical Stabilizers on the Number of *Merlinda spp.* Germinations Per Pot.

Treats	Conc.*	Number of Germinations After Days From Cultivation						
		3	6	9	12	15	18	21
PVA1	0.2%	0	12	25	25	25	25	25
		0	5	23	23	23	23	23
		0	1	21	21	21	21	21
PVA1	0.4%	0	5	21	21	23	23	23
		0	2	20	21	24	24	24
		0	1	18	22	24	24	24
PVA2	0.2%	0	4	21	24	24	24	24
		0	17	21	21	21	21	21
		0	1	20	22	23	23	23
PVA2	0.4%	0	13	23	23	24	24	24
		0	17	24	24	24	24	24
		0	13	23	23	23	23	23
PEG3	0.2%	0	10	18	21	23	23	23
		0	13	21	21	21	22	23
		0	15	21	21	22	22	22
PEG3	0.4%	0	12	23	24	24	24	24
		0	14	22	22	23	23	23
		0	12	23	23	24	24	24
PEG4	0.2%	0	6	25	25	25	25	25
		0	17	24	24	24	24	25
		0	13	24	24	25	25	25
PEG4	0.4%	0	17	22	22	22	22	22
		0	20	21	22	23	23	23
		0	12	21	24	25	25	25
V1	0.05 l m^{-2}	0	13	24	24	24	24	24
		0	22	23	23	23	23	23
		0	21	25	25	25	25	25
V1	0.10 l m^{-2}	0	15	22	22	22	22	22
		0	20	24	25	25	25	25
		0	3	21	21	21	23	23
V2	0.05 l m^{-2}	0	3	21	23	23	23	23
		0	12	22	22	22	22	22
		0	14	22	24	25	25	25
V2	0.10 l m^{-2}	0	9	19	20	20	20	20
		0	6	22	22	22	22	22
		0	3	18	21	22	22	22

Continued Table 5.42

Treats	Conc.*	Number of Germinations After Days From Cultivation						
		3	6	9	12	15	18	21
V3	0.05 l m^{-2}	0	0	20	22	23	23	23
		0	1	22	23	23	23	23
		0	1	19	20	21	21	21
V3	0.10 l m^{-2}	0	8	22	23	23	23	23
		0	13	20	22	22	23	23
		0	18	24	24	24	24	24
F.E.	0.2 l m^{-2}	0	11	19	22	22	23	23
		0	2	25	25	25	25	25
		0	9	25	25	25	25	25
F.E.	0.4 l m^{-2}	0	5	20	23	23	23	23
		0	9	22	22	23	23	23
		0	1	23	25	25	25	25
B.E.	0.5 l m^{-2}	0	1	19	23	23	23	23
		0	11	23	23	23	23	23
		0	5	20	22	22	22	22
B.E.	1.0 l m^{-2}	0	3	20	21	22	22	22
		0	3	21	23	23	23	23
		0	9	15	17	18	18	18
Aq1	0.33%	0	19	23	23	24	24	24
		0	20	23	23	23	23	23
		0	18	21	21	21	22	22
Aq1	0.66%	0	6	16	21	22	23	23
		0	20	23	23	23	23	23
		0	17	22	23	23	23	23
Aq2	200 gm m^{-2}	0	10	21	21	21	23	24
		0	17	23	23	24	24	24
		0	8	14	14	17	18	18
Aq2	250 gm m^{-2}	0	8	13	17	17	20	20
		0	14	15	16	17	17	17
		0	16	19	19	19	20	20
Control		0	6	22	22	23	23	23
		0	8	24	24	24	24	24
		0	10	20	21	23	23	23

* All (%) are on the base of air-dry sand.

Table 5.43: Effect of Various Chemical Stabilizers on the Number of *Melion spp.* Germinations Per Pot.

Treats	Conc.*	Number of Germinations After Days From Cultivation						
		3	6	9	12	15	18	21
PVA1	0.2%	0	21	22	22	22	22	22
		0	15	22	22	22	22	22
		0	22	24	25	25	25	25
PVA1	0.4%	0	10	20	21	21	21	22
		0	16	20	21	21	21	21
		0	11	22	22	22	22	22
PVA2	0.2%	0	2	22	22	23	23	23
		0	1	20	22	22	22	22
		0	15	24	24	24	24	24
PVA2	0.4%	0	21	24	24	24	24	24
		0	19	23	23	23	23	23
		0	9	23	23	23	23	23
PEG3	0.2%	0	3	19	23	24	25	25
		0	5	23	23	23	24	24
		0	12	23	24	24	24	24
PEG3	0.4%	0	16	21	22	22	22	22
		0	3	23	23	24	24	24
		0	11	21	22	22	22	22
PEG4	0.2%	0	1	21	23	24	24	24
		0	0	22	24	24	24	24
		0	7	21	22	22	22	22
PEG4	0.4%	0	9	22	24	24	24	24
		0	9	23	23	24	24	24
		0	12	25	25	25	25	25
V1	0.05 l m^{-2}	0	12	22	23	23	23	23
		0	7	21	23	23	23	23
		0	3	21	22	22	22	22
V1	0.10 l m^{-2}	0	0	21	24	24	24	24
		0	7	20	21	21	21	21
		0	6	21	23	23	23	23
V2	0.05 l m^{-2}	0	10	20	21	21	21	21
		0	21	23	24	24	24	24
		0	21	23	23	23	23	23
V2	0.10 l m^{-2}	0	15	21	23	25	25	25
		0	6	22	23	24	24	24
		0	16	22	23	23	23	23

Continued Table 5.43

Treats	Conc.*	Number of Germinations After Days From Cultivation						
		3	6	9	12	15	18	21
V3	0.05 l m^{-2}	0	14	23	24	25	25	25
		0	15	20	20	21	21	21
		0	20	20	20	23	23	23
V3	0.10 l m^{-2}	0	9	20	22	22	22	22
		0	12	25	25	25	25	25
		0	13	24	24	24	24	24
F.E.	0.2 l m^{-2}	0	5	23	24	24	24	24
		0	11	25	25	25	25	25
		0	12	23	25	25	25	25
F.E.	0.4 l m^{-2}	0	2	24	25	25	25	25
		0	4	21	22	23	23	23
		0	10	24	25	25	25	25
B.E.	0.5 l m^{-2}	0	7	21	21	21	21	21
		0	7	21	22	23	23	23
		0	9	23	24	25	25	25
B.E.	1.0 l m^{-2}	0	18	25	25	25	25	25
		0	18	22	23	23	23	23
		0	14	22	23	24	24	24
Aq1	0.33%	0	21	22	22	23	23	23
		0	22	24	24	24	24	24
		0	21	21	21	21	21	21
Aq1	0.66%	0	21	21	22	23	23	23
		0	24	24	24	24	24	24
		0	24	25	25	25	25	25
Aq2	200 gm m^{-2}	0	17	18	18	18	19	19
		0	19	21	21	21	21	21
		0	12	21	21	21	22	22
Aq2	250 gm m^{-2}	0	10	18	19	19	19	19
		0	14	21	22	22	23	23
		0	22	23	23	23	23	23
Control		0	14	21	23	23	23	23
		0	15	24	24	24	24	24
		0	14	24	25	25	25	25

* All (%) are on the base of air-dry sand.

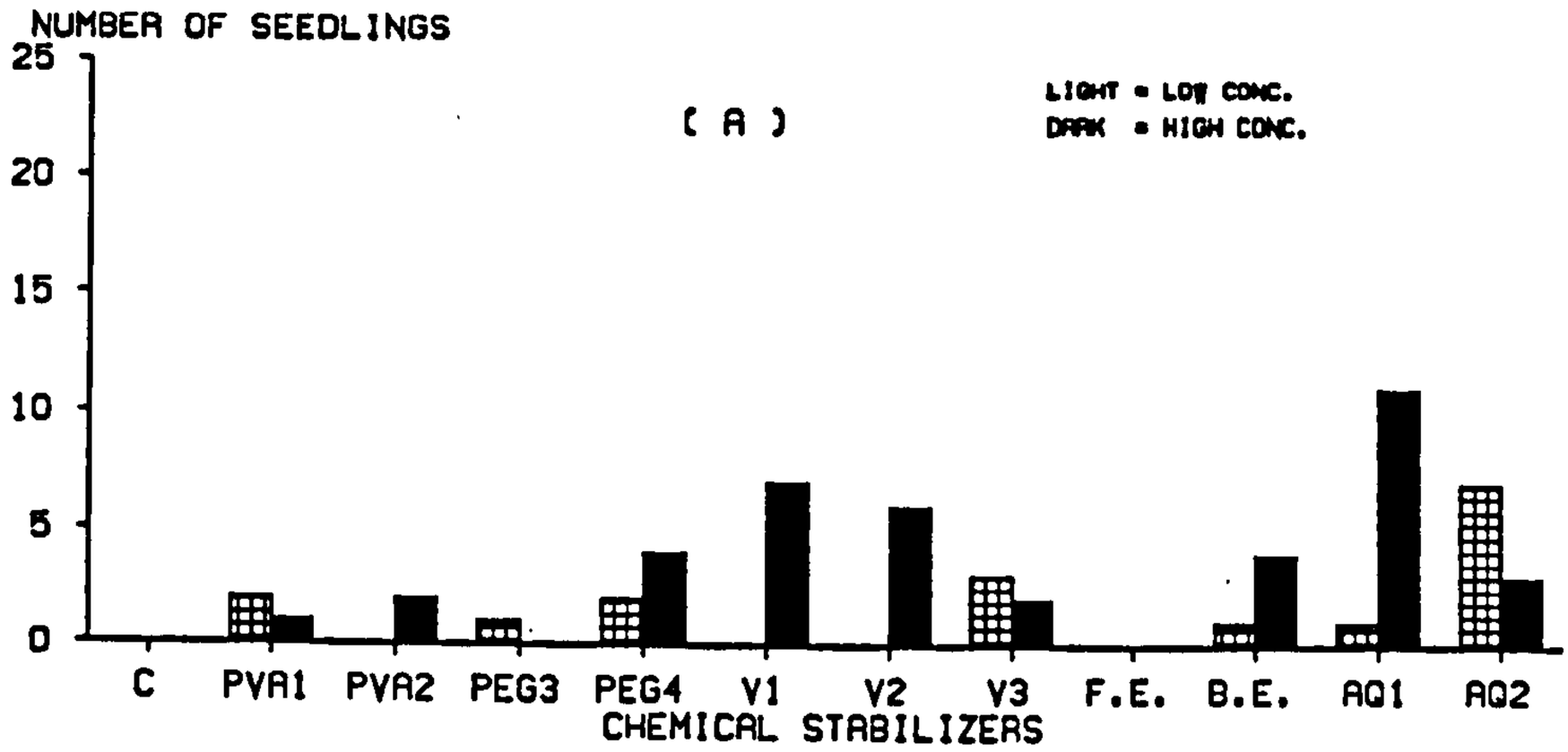
Table 5.44: Effect of Various Chemical Stabilizers on the Number of Marram Grass Germinations Per Pot.

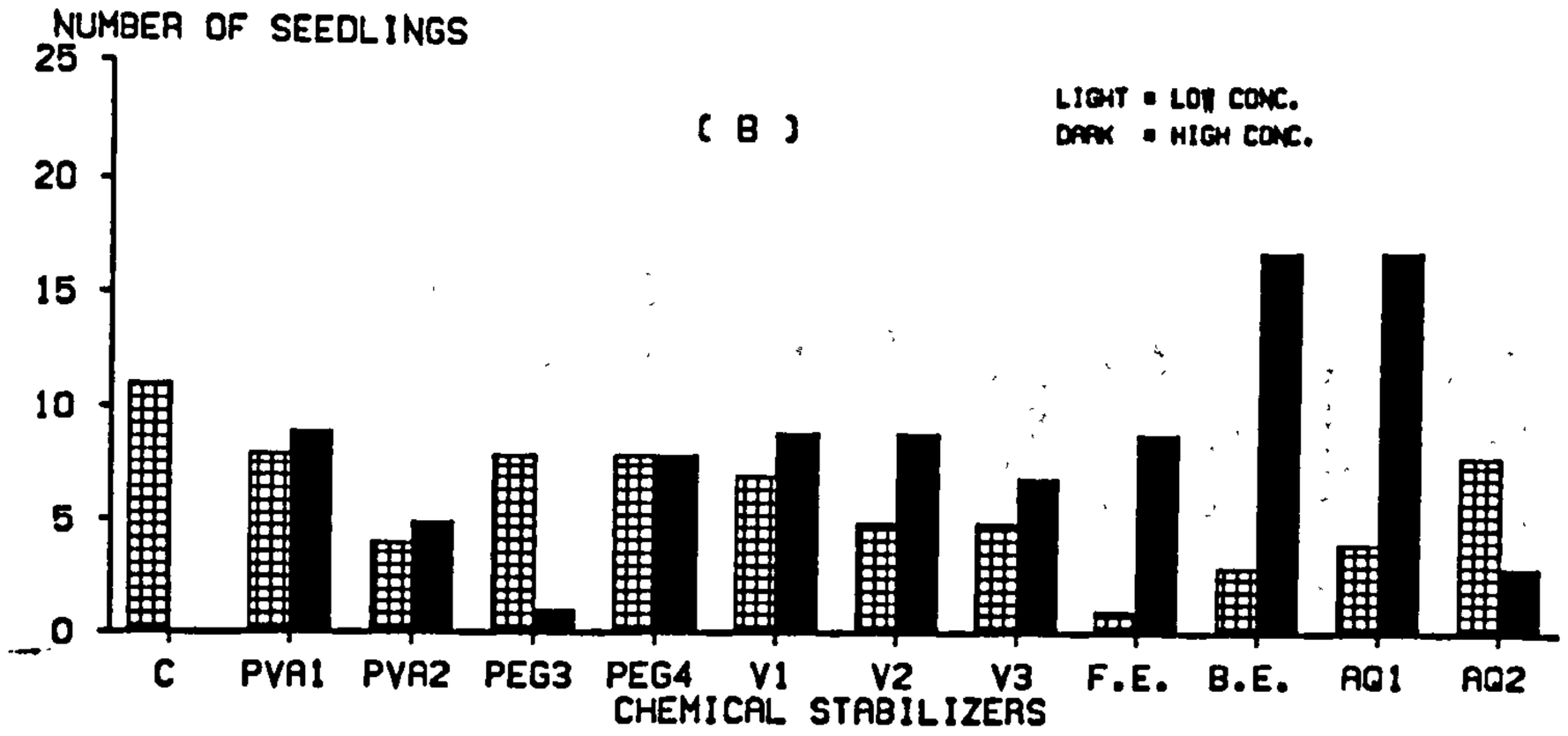
Treats	Conc.*	Number of Germinations After Days From Cultivation						
		3	6	9	12	15	18	21
PVA1	0.2%	0	0	0	12	23	24	24
		0	0	0	13	18	22	22
		0	0	0	3	18	21	23
PVA1	0.4%	0	0	0	12	16	19	23
		0	0	0	12	20	21	21
		0	0	0	7	13	18	19
PVA2	0.2%	0	0	0	20	22	22	22
		0	0	12	23	24	24	24
		0	0	6	16	19	20	20
PVA2	0.4%	0	0	9	9	18	21	23
		0	0	6	19	23	23	23
		0	0	3	14	19	20	22
PEG3	0.2%	0	0	8	18	18	18	18
		0	0	12	21	21	22	22
		0	0	16	21	21	21	21
PEG3	0.4%	0	0	2	12	17	17	17
		0	0	14	22	22	22	22
		0	0	6	19	19	19	19
PEG4	0.2%	0	0	13	21	21	21	21
		0	0	14	18	19	19	19
		0	0	7	21	23	23	23
PEG4	0.4%	0	0	1	17	18	18	20
		0	0	11	21	23	23	23
		0	0	10	19	19	20	21
V1	0.05 l m^{-2}	0	0	8	19	21	21	21
		0	0	6	20	22	24	25
		0	0	5	18	20	20	20
V1	0.10 l m^{-2}	0	0	1	20	21	21	21
		0	0	9	20	20	20	20
		0	0	4	20	23	23	23
V2	0.05 l m^{-2}	0	0	8	21	24	24	24
		0	0	6	21	22	22	22
		0	0	6	22	24	24	24
V2	0.10 l m^{-2}	0	0	0	13	18	21	21
		0	0	3	18	22	22	22
		0	0	1	10	17	20	20

Continued Table 5.44

Treats	Conc.*	Number of Germinations After Days From Cultivation						
		3	6	9	12	15	18	21
V3	0.05 l m^{-2}	0	0	8	20	22	22	23
		0	0	2	17	21	21	21
		0	0	3	17	18	18	18
V3	0.10 l m^{-2}	0	0	2	15	20	21	21
		0	0	4	18	22	22	22
		0	0	2	13	19	22	22
F.E.	0.2 l m^{-2}	0	0	8	20	21	21	21
		0	0	3	14	20	22	22
		0	0	1	11	15	18	18
F.E.	0.4 l m^{-2}	0	0	0	0	4	5	20
		0	0	0	0	7	13	20
		0	0	0	1	5	9	15
B.E.	0.5 l m^{-2}	0	0	5	16	19	20	20
		0	0	4	11	15	18	20
		0	0	1	12	16	21	22
B.E.	1.0 l m^{-2}	0	0	0	12	17	23	25
		0	0	0	10	17	22	22
		0	0	1	13	15	18	18
Aq1	0.33%	0	0	4	17	19	20	20
		0	0	5	22	23	23	23
		0	0	1	15	20	20	20
Aq1	0.66%	0	0	1	18	23	23	23
		0	0	1	12	19	19	19
		0	0	4	17	23	23	24
Aq2	200 gm m^{-2}	0	0	0	16	19	21	21
		0	0	0	15	19	23	24
		0	0	0	5	11	20	21
Aq2	250 gm m^{-2}	0	0	0	1	5	7	15
		0	0	0	2	5	13	20
		0	0	0	5	8	17	20
Control		0	0	3	20	20	20	20
		0	0	4	21	21	21	21
		0	0	4	13	13	17	19

* All (%) are on the base of air-dry sand.





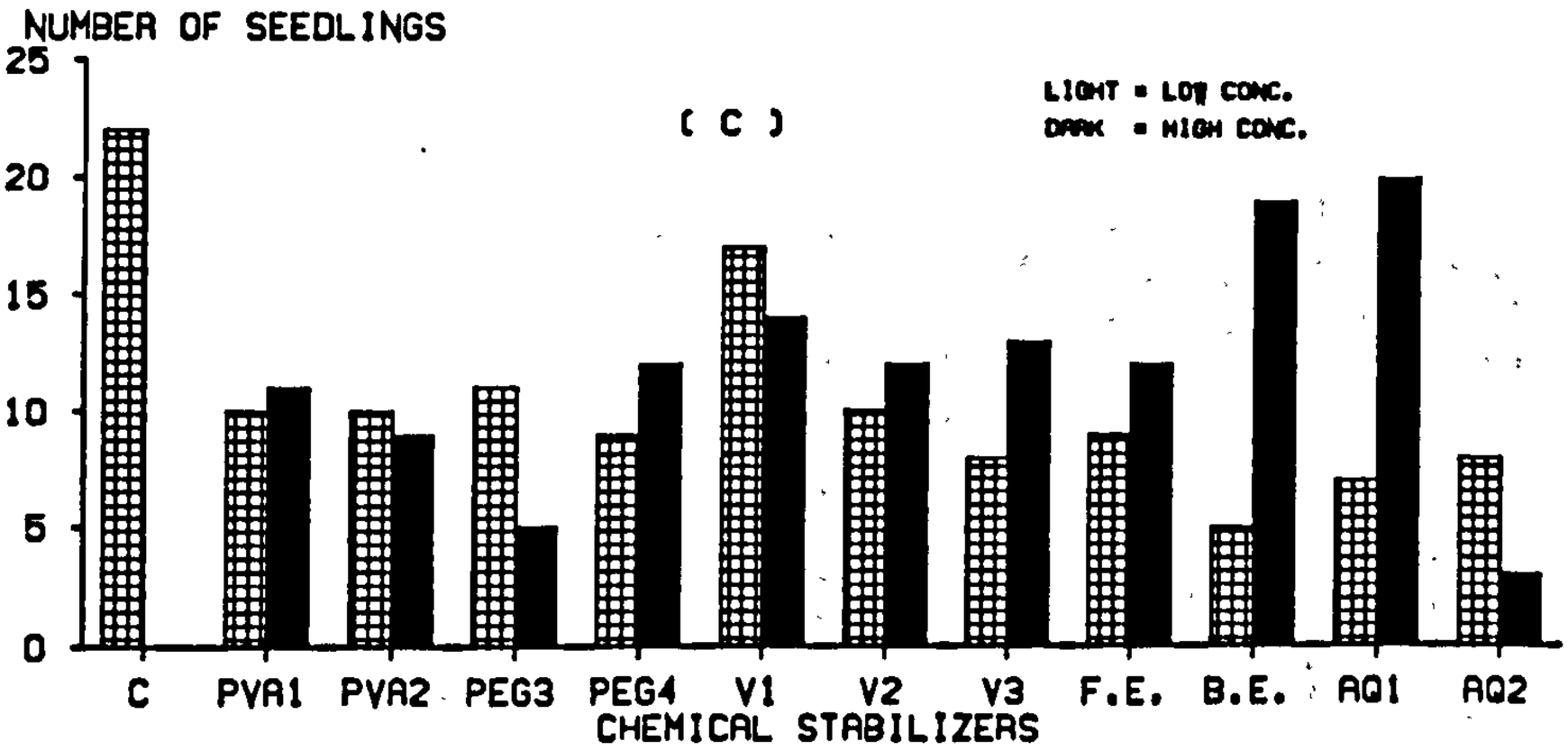
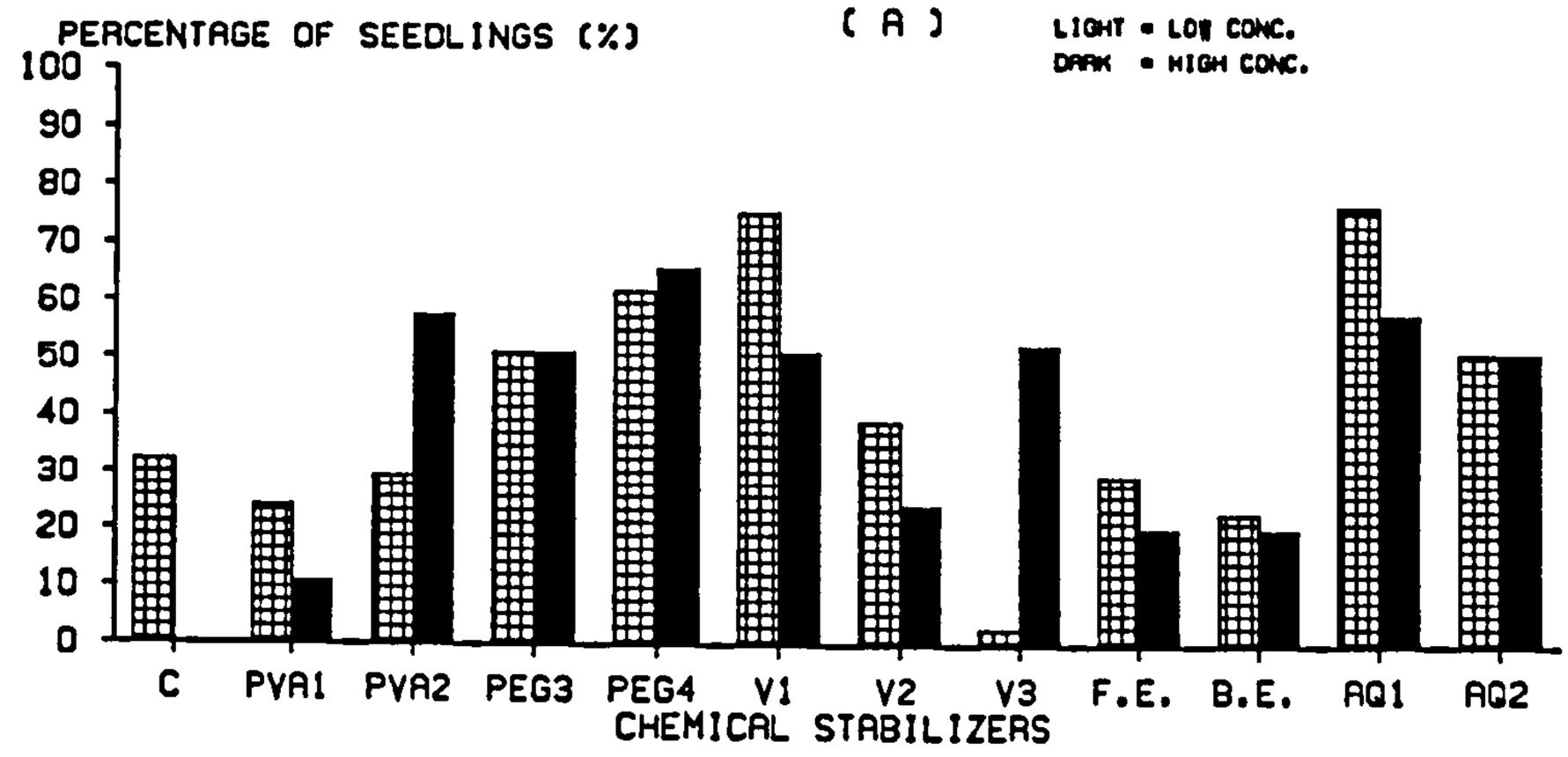
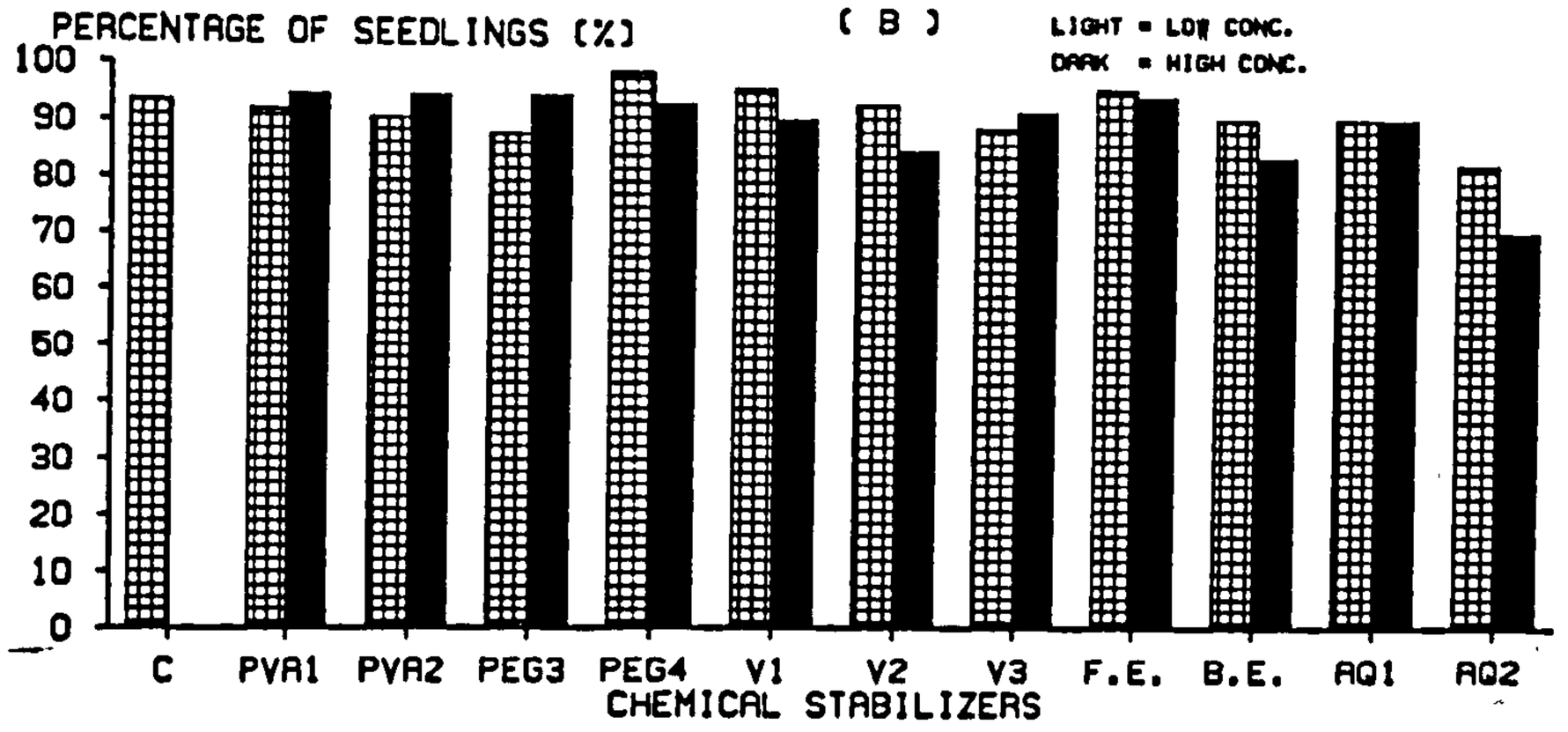


FIG. 5.54: TOTAL NUMBER OF PANICUM SPP. SEEDLINGS AFTER (A): 9 DAYS; (B): 15 DAYS; (C): 21 DAYS OF PLANTING IN DRURIDGE BAY SAND AS AFFECTED BY VARIOUS CONDITIONERS TREATMENTS





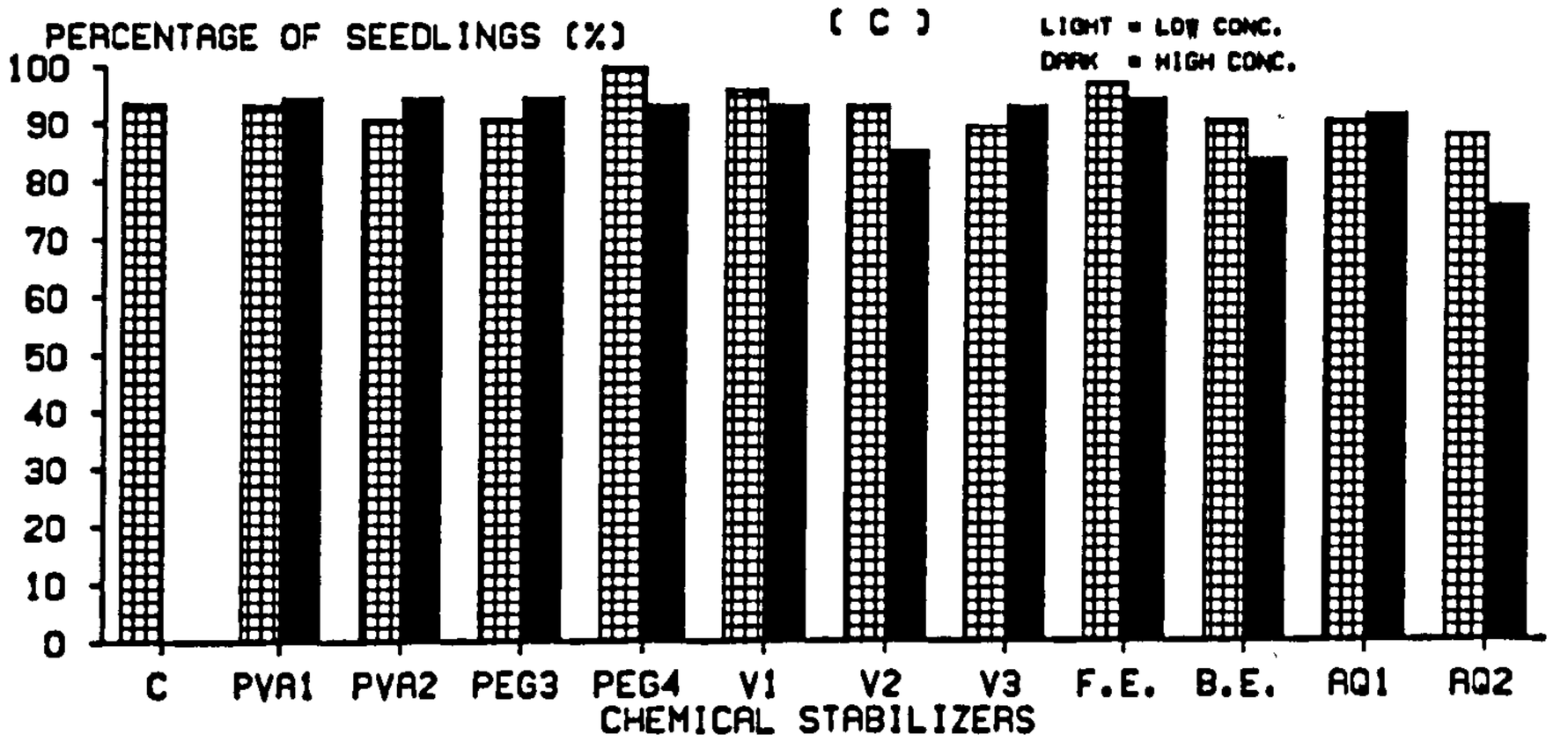


FIG. 5.55: PERCENTAGE OF MERLINDA SPP. SEEDLINGS AFTER (A): 6 DAYS; (B): 15 DAYS; (C): 21 DAYS OF PLANTING IN DRURIDGE BAY SAND AS AFFECTED BY VARIOUS CONDITIONERS TREATMENTS

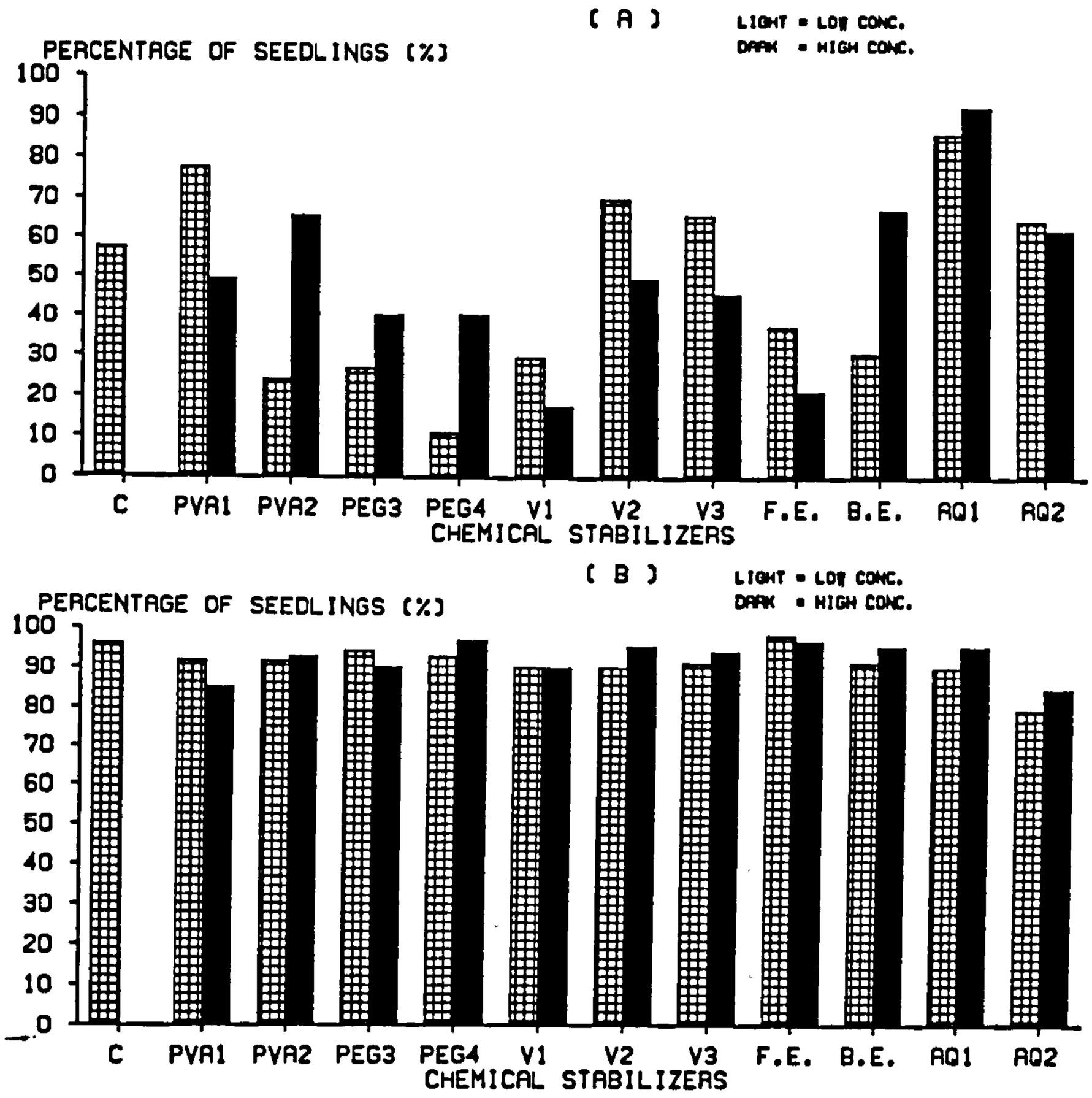


FIG. 5.56: PERCENTAGE OF MELION SPP. SEEDLINGS AFTER (A): 6 DAYS; (B): 15 DAYS; (C): 21 DAYS OF PLANTING IN DRURIDGE BAY SAND AS AFFECTED BY VARIOUS CONDITIONERS TREATMENTS

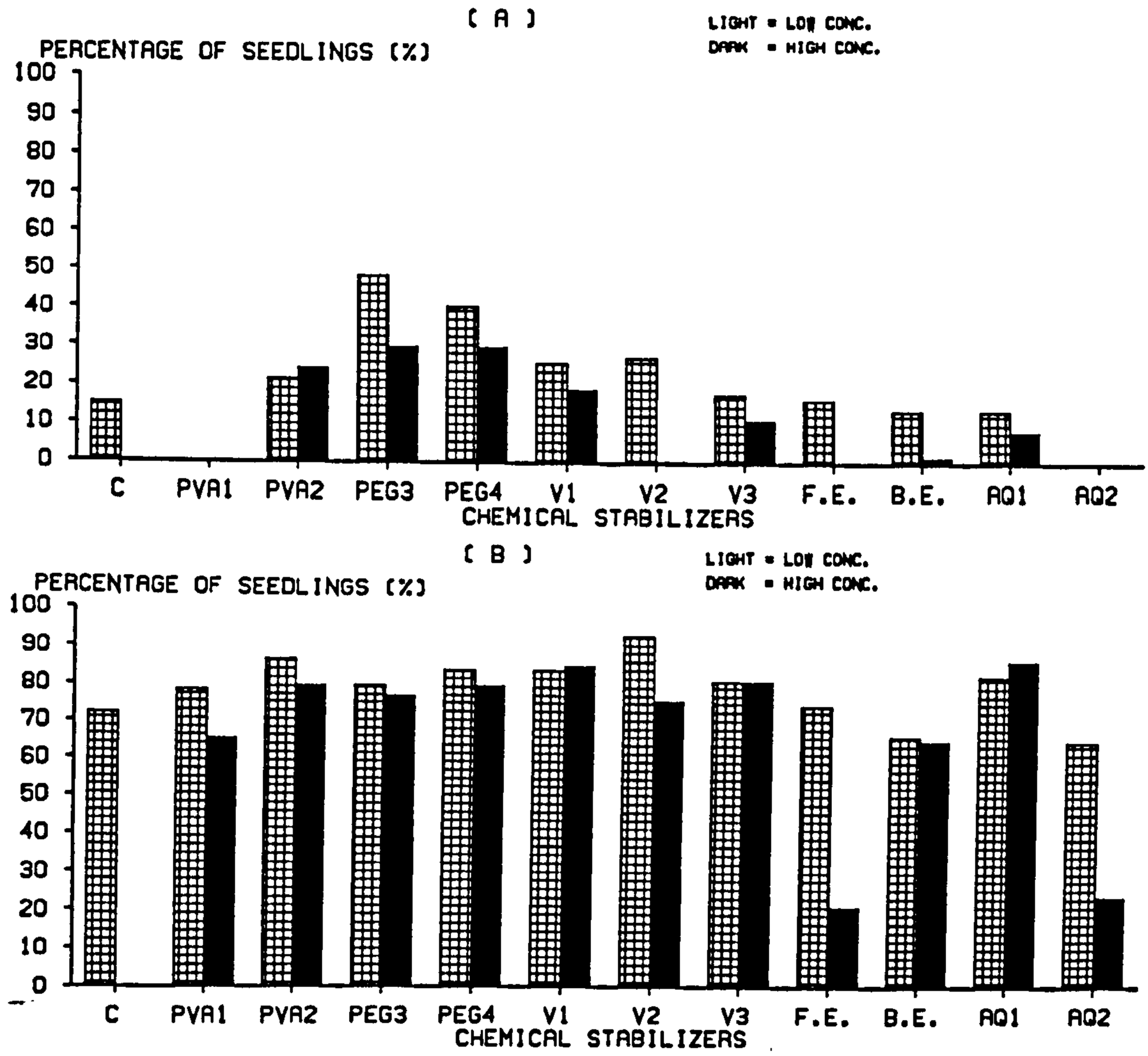


FIG. 5.57: PERCENTAGE OF MARRAM GRASS SEEDLINGS AFTER (A): 9 DAYS; (B): 15 DAYS; (C): 21 DAYS OF PLANTING IN DRURIDGE BAY SAND AS AFFECTED BY VARIOUS CONDITIONERS TREATMENTS

(0.10 l m^{-2}); PVA1 (0.4%) and PEG3 (0.2%); PVA1 (0.2%) and PVA2 (0.2%) and V2 (0.05 l m^{-2}); PVA2 (0.4%) and PEG4 (0.4%) and F.E. (0.2 l m^{-2}); V3 (0.05 l m^{-2}) and Aq2 (200 gm m^{-2}) and B.E. (0.5 l m^{-2}); Aq1 (0.33%); PEG3 (0.4%); with Aq2 (250 gm m^{-2}) having the most limiting effect on germination. These results show no definite pattern as sometimes it is the higher concentrations with depress germination eg. Aq2 (250 gm m^{-2}) whilst with other stabilizers it is the lower concentration which have most effect eg. Aq1 (0.33%). In most cases germination rates showed little increase after 15 days.

For the rye grass (*Merlinda spp.*), the PVA2 (0.4%); PEG3 (0.2% and 0.4%); PEG4 (0.2% and 0.4%); V1 (0.05 and 0.10 l m^{-2}); V2 (0.05 l m^{-2}); V3 (0.10 l m^{-2}); Aq1 (0.33% and 0.66%) and Aq2 (200 and 250 gm m^{-2}) treatments all increased germination rates in the first six days. After 21 days however the pattern had changed considerably, only PEG4 (0.2%); F.E. (0.2 l m^{-2}) and V1(0.05 l m^{-2}) had germination rates significantly higher than the control; PVA1 (0.4%); PVA2 (0.4%); PEG3 (0.4%); V3 (0.10 l m^{-2}) and F.E. (0.4 l m^{-2}) germination rates were slightly above the control (mean 23.6 as against 23.3). Of the remainder only V2 (0.10 l m^{-2}); B.E. (1.0 l m^{-2}); Aq2 (200 and 250 gm m^{-2}) had significantly reduced germination rates. As with *Panicum spp.* trial, these appears to be no destinct pattern, though the highest treatment germinations related to the lower concentration levels and the least successful treatments coincided with the higher concentrations. This suggests that there is a possible link between temperature and infiltration rates and possibly some effect on the 'hardness' or thickness of the surface cap produced by the chemicals, this is especially so for Aq2 (see sections 5.1.2 and 5.1.3).

PVA1 (0.2%); PVA2 (0.4%); V2 (0.05 l m^{-2}); V3 (0.05 l m^{-2}); B.E. (1.0 l m^{-2}); Aq1 (0.33% and 0.66%) and Aq2 (200 and 250 gm m^{-2}) all increased germination of *Melion spp.* in the first 6 days. After 21 days the pattern of germination have changed somewhat, PEG3 (0.2%); PEG4 (0.4%) and F.E. (0.2

and 0.4 l m^{-2}) have slightly higher germination rates than the control, all other treatments resulted in decreased germination with the greatest reduction under Aq2 (200 and 250 gm m^{-2}), a direct contrast to the situation after 6 days. As previously there is no apparent pattern to the effect of the chemicals on germination rates, similarly little change occurs in the number of germinations after 15 days.

In the case of marram grass (*Ammophelia arenaria*) PVA2 (0.2% and 0.4%); PEG3 (0.2% and 0.4%); PEG4 (0.2% and 0.4%); V1 (0.05 and 0.10 l m^{-2}); V2 (0.05 l m^{-2}); V3 (0.05 l m^{-2}) and F.E. (0.2 l m^{-2}) increased germintion over the first 9 days. However by 21 days most treatments had germination rates higher than that of the control, the only exceptions being PEG3 (0.4%) and Aq2 (250 gm m^{-2}). Once again there is no obvious explanation for these changes in germination rates.

In conclusion, the germination rate experiments reveal a complex set of relationships between individual stabilizers, the concentration of these applied and the four different species tested. Essentially however, after 21 days, in most instances the difference in germination rates between the untreated and treated samples was relatively small. Aq2 (200 and 250 gm m^{-2}) is the only treatment that consistently produced markedly lowered germination rates over a 21 day period. An analysis of those treatments which gave enhanced germination rates for *Merlinda spp.*; *Melion spp.* and marram grass shows only two treatments are common to all namely F.E. (0.2 and 0.4 l m^{-2}). Despite this none of the treatments prevented germination of any of the four species. Photos 5.24 - 5.26 show for example, the growth of the *Melion spp.* seedlings in Druridge Bay sand treated by F.E.; B.E. and Aq1 respectively.

Statistical analysis (appendix tables 5.17 -5.25) shows the following:-

1. Although highly significant differences between the number of germinations under the effect of various treatments were found for both *Merlinda spp.* and

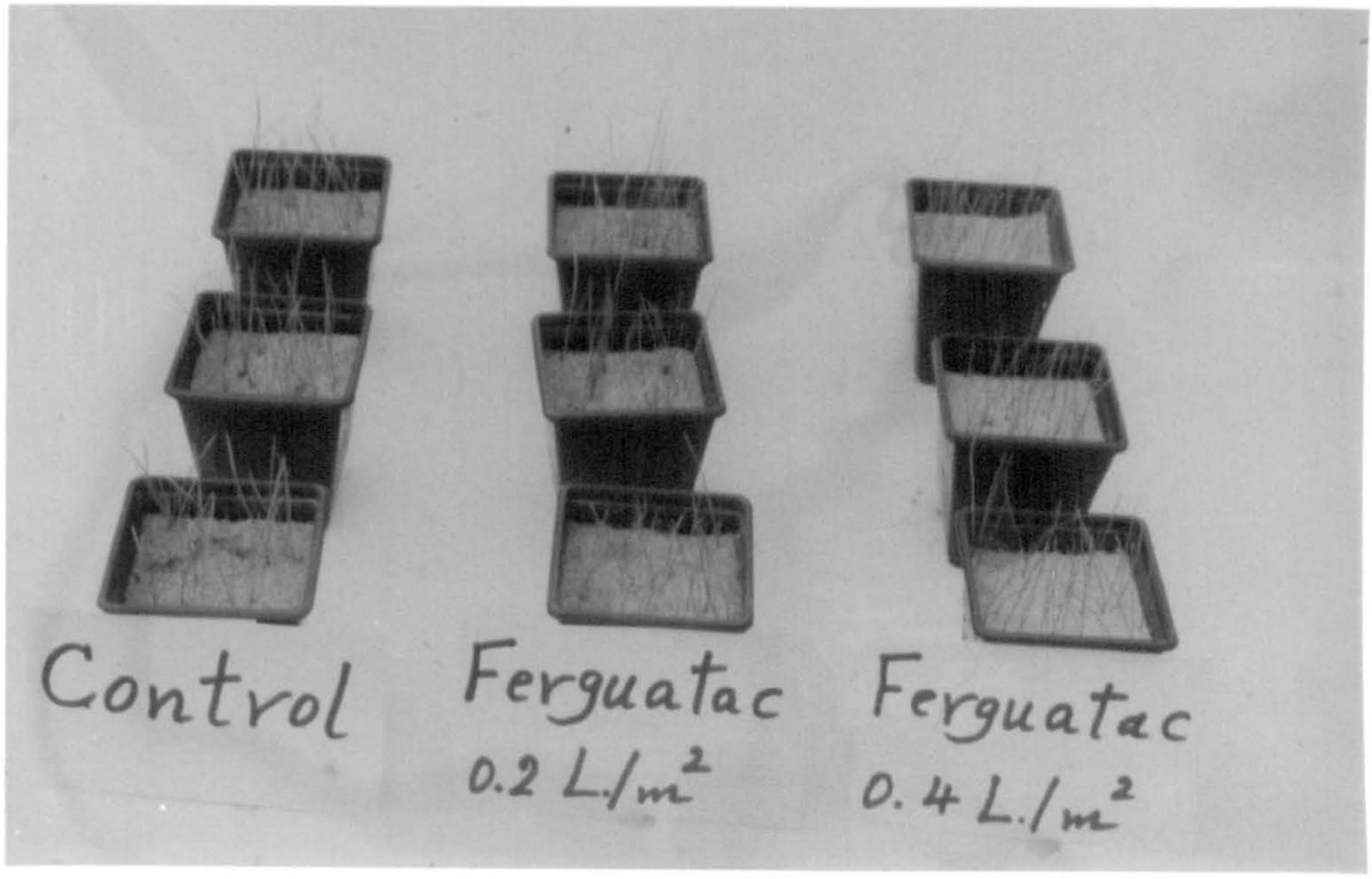


Plate 5.24: Growth of *Melion spp.* in Druridge Bay Sand Samples Treated With F.E. (30 Days After Planting).

Melion spp. in the first 6 days from cultivation, as Fcal (3.37 and 5.14) respectively for *Merlinda spp.* and *Melion spp.* were larger than Ftab. (2.27) at the 1% level of significance (appendix tables 5.17 and 5.18), the individual 95% confidence intervals (CI's) for mean based on pooled standard deviation (Ryan et al., 1985) indicated that only Aq1 (0.33%) in the case of the *Merlinda spp.* significantly increased the number of germinations when compared with the control, and only PEG4 (0.2%) and V1 (0.1 l m^{-2}) in the case of the *Melion spp.* significantly reduced the number of germinations. The other teatments, although all had some effect on germination, none of them was significantly different from the control. After 21 days of cultivation, the situation changed, only Aq2 (250 gm m^{-2}) and Aq2 (200 gm m^{-2}) in the cases of *Merlinda spp.* and *Melion spp.* respectively, significantly reduced the number of germinations in comparison with the control (appendix tables

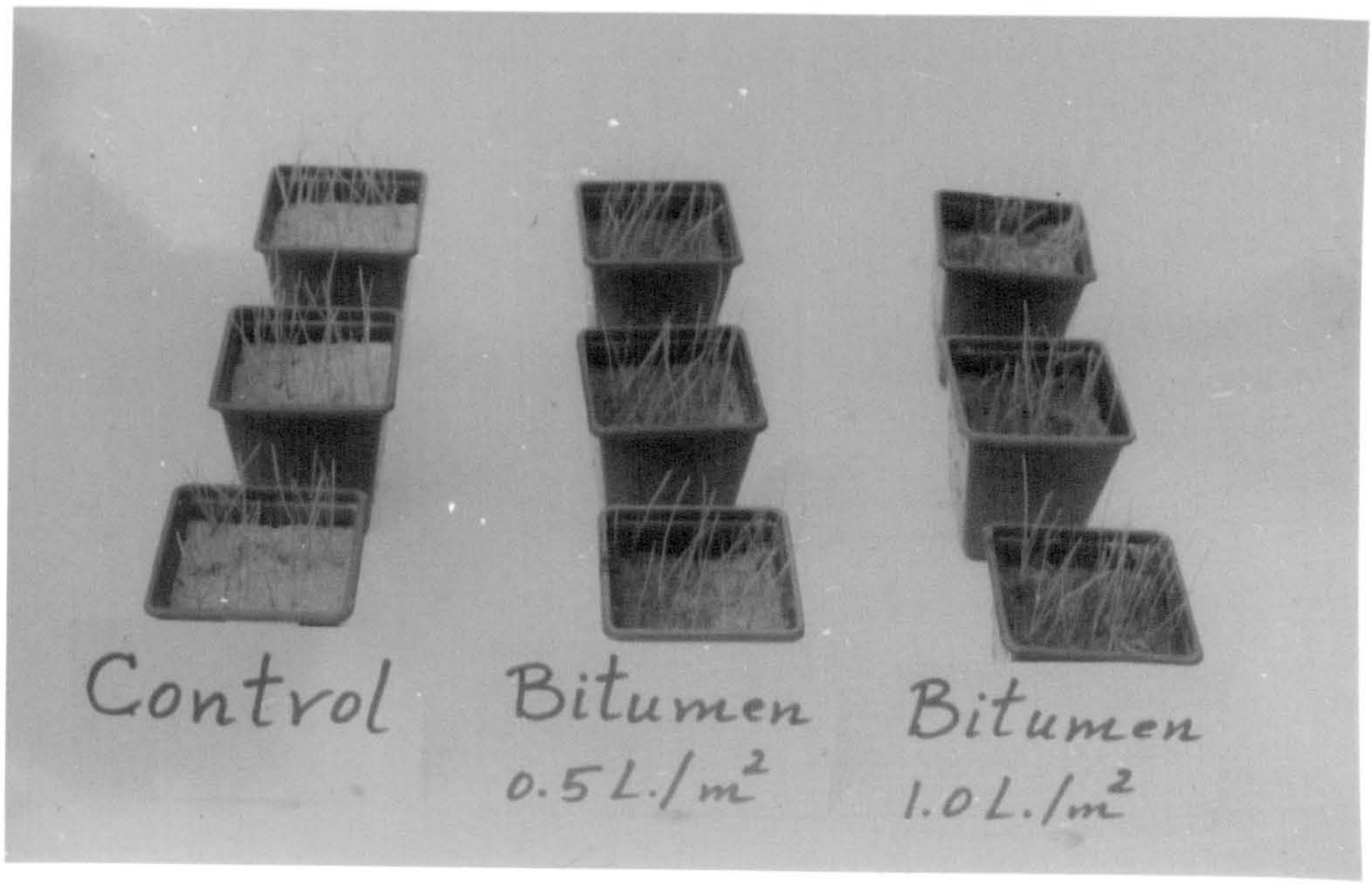


Plate 5.25: Growth of *Melion spp.* in Druridge Bay Sand Samples Treated With B.E. (30 Days After Planting).

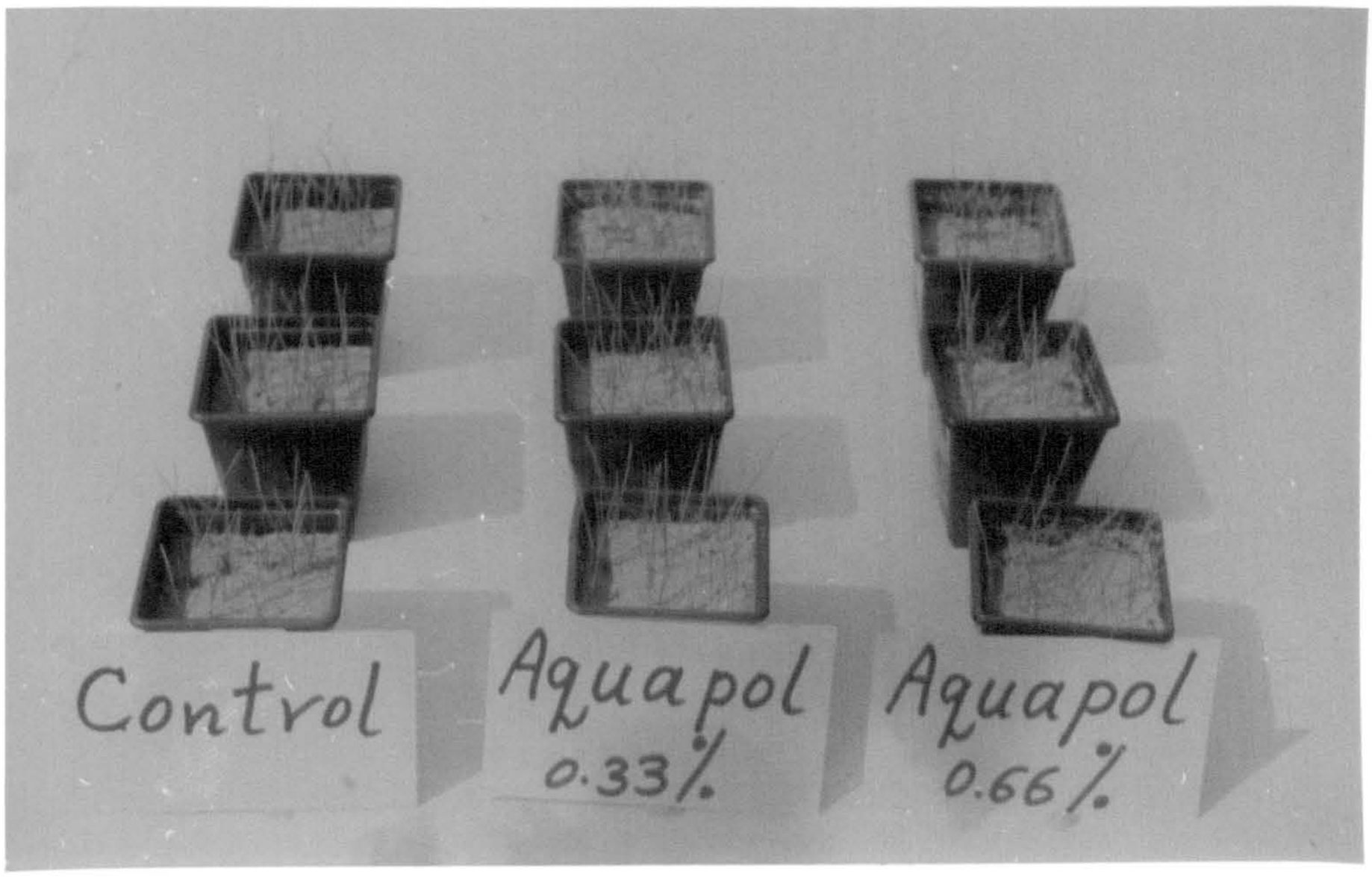


Plate 5.26: Growth of *Melion spp.* in Druridge Bay Sand Samples Treated With Aq1 (30 Days After Planting).

5.19 and 5.20). The effects of all the other treatments on both species were not significant.

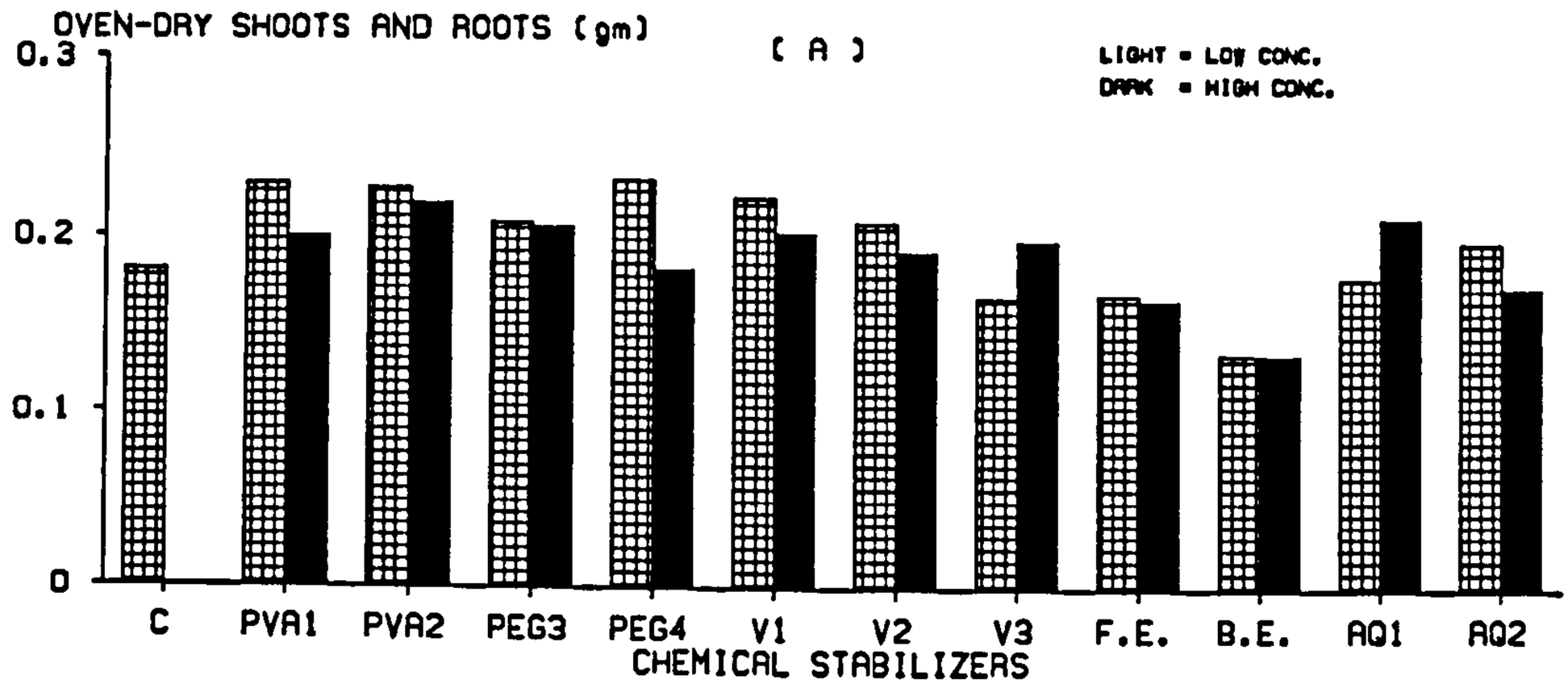
2. As with *Merlina spp.* and *Melion spp.* trials, the differences in the case of the marram grass experiment were also very significant in both first 9 and 12 days from cultivation, as Fcal (4.16 and 8.05) respectively, were larger than Ftab. (2.27) at the 1% level of significance (appendix tables 5.21 and 5.22). The individual 95% CI's for mean based on pooled standard deviation indicated that only PEG3 (0.2%) and PEG4 (0.2%) gave significant increases in the first 9 days from cultivation; whilst, after 12 days, PVA1 (0.2% and 0.4%); F.E. (0.4 l m^{-2}) and Aq2 (250 gm m^{-2}) were the only treatments that significantly reduced the number of germinations. None of the other treatments after either 9 days or 12 days differ significantly from the control. However, after 21 days from cultivation, none of the chemical treatments differ significantly from the control (appendix table 5.23).
3. In the case of the *Panicum spp.*, the differences between the number of germinations in the first 9 days were almost significant at the 5% level of significance. Fcal. (1.76) was almost the same as Ftab. (1.78). The individual 95% CI's for mean based on pooled standard deviation indicated that only Aq1 (0.66%) increased the number of germinations significantly higher than the control (appendix table 5.24). After 21 days from cultivation, however, the situation is changed and the control gave the highest germination numbers but was only significantly higher than PEG3 (0.4%); B.E. (0.5 l m^{-2}) and Aq2 (250 gm m^{-2}) (appendix table 5.25).

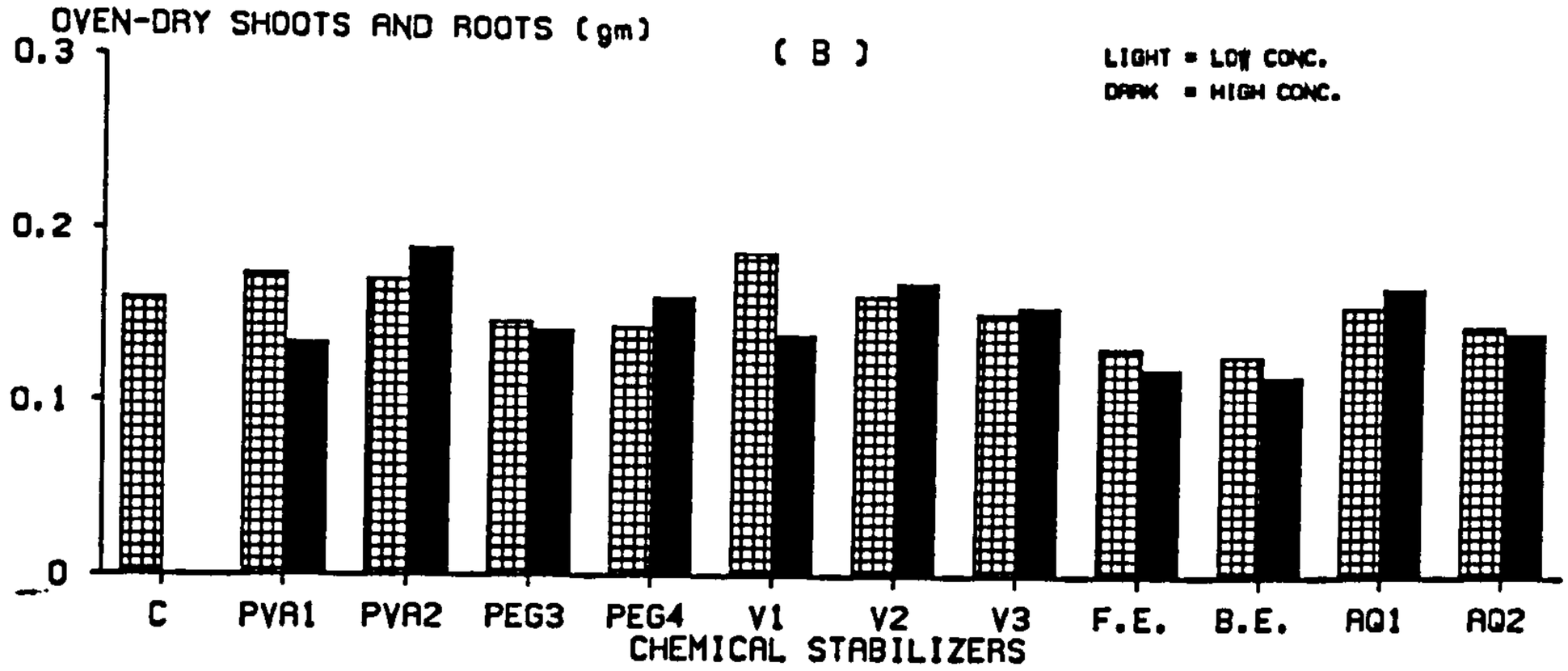
The cause of the decreased germination rates is not obvious, in most cases it would appear to be a complex interaction of temperature and moisture availability. For marram grass however, reduced seedling emergence seemed to be at least partially linked to the difficulty of the seedlings breaking through the surface crust produced by the various stabilizers, especially Aq2.

b. Effect of Chemical Stabilizers on the Dry-Weights of Seedlings 30 Days After Planting:

The data obtained from measuring the oven-dry weights of the shoots and roots of *Merlinda spp.; Melion spp.* and marram grass, 30 days after planting illustrated in figures (5.58). *Panicum spp.* was neglected in this investigation due to its very low germination percentages and therefore the very low weights of shoots and roots. From figure (5.58), the following points can be concluded:

1. The oven-dry weights for the *Merlinda spp.* under the effect of all chemical treatments were higher than those of *Melion spp.* and marram grass seedlings.
2. Compared with the control, B.E. 0.5 and 1.0 l m^{-2}followed by F.E. 0.2 and 0.4 l m^{-2}were the only chemicals that clearly reduced the oven-dry weights of *Melion spp.* plants. In the case of the *Merlinda spp.*, only B.E. 0.5 and 1.0 l m^{-2}obviously reduced the oven-dry weights of the plants. Whilst, in the case of the marram grass seedlings, both F.E. 0.4 l $m^{-2}$and Aq2 250 gm m^{-2}were the only treatments that obviously reduced the weights. The reductions were possibly due to the effect of the hard surface crusts created by the application of these chemicals to the sand surface, which therefore restricted the growth of the young seedlings of these three plants.
3. PVA1; PEG3; V1; F.E.; B.E. and Aq2 reduced the oven-dry weights of all three plants (*Merlinda spp., Melion spp.* and marram grass) as the chemicals concentrations increased. Aq1 behaved exactly the contrast with all three plants, the lower concentration reduced yields more than the higher concentration. Whilst, the increases in the concentrations of PVA2; PEG4; V2 and V3 had little effect.
4. Although the statistical analysis of the plants oven-dry weights under the effect of various chemical treatments and the control indicated a highly significant difference between these treatments at the 1% level of significance, as





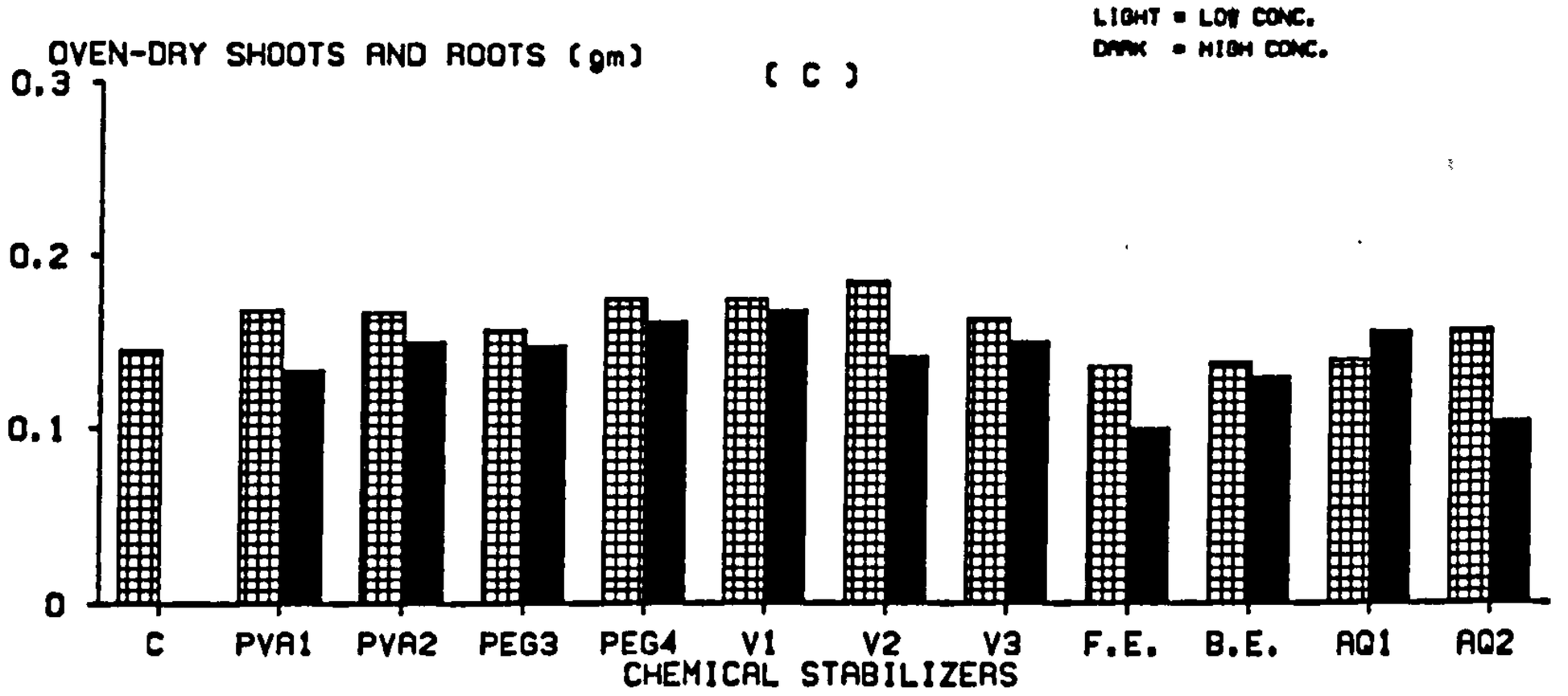


FIG. 5.58: MEAN WEIGHTS OF OVEN-DRY SHOOTS AND ROOTS OF (A): MERLINDA SPP.; (B): MELION SPP.; (C): MARRAM GRASS SEEDLINGS AFTER 30 DAYS FROM TREATMENT BY VARIOUS CHEMICAL CONDITIONERS

Fcal values (2.79; 2.54 and 2.90) respectively for the *Merlinda spp.; Melion spp.* and marram grass plants oven dry weights, were larger than the Ftab (2.27) (appendix tables 5.26 - 5.28), the individual 95% CI's for mean based on pooled standard deviation shows that no significant differences between the oven-dry shoots and roots of the control samples and those of all chemical treatments were obtained.

5.2.3 Effect of the Selected Chemical Stabilizers on Plant Growth

5.2.3.1 Theoretical Basis

As with their effect on the germination and seedling emergence, soil chemical stabilizers, can either increase or decrease the growth of any plant species in the soil (Carr and Greenland, 1975; De Waele, 1976a; 1976b; Gupta and Aggarwal, 1980; and Al-Debagi, 1983).

Many workers concluded that the use of polyethylene film gives excellent results in establishing a cover of crop (Py and Barbier, 1966; Py, 1968; and Charpentier et al., 1970).

Kerchev et al. (1976) indicated that the increase in corn (maize) products in a calcareous chernozem soil under the effect of alkylammonium chloride (RNH2-HCl, where R = C18-C20) and polyethylene mulches, was due to the presence of available water of high potential as a result of the reduction in water evaporation under mulches.

In simulated sodic and natural sandy loam soils treated with (0.03 to 0.12% by weight) PVAc emulsions, Carr and Greenland (1975) found that yields of rye grass, tomato, and barley increased significantly over untreated controls grown in soil of the same aggregate size distribution.

In Egyptian sandy soil "super gel" treatments led to an increase in germination percent and rate, plant height, and dry matter production of corn plants

(El-Hady et al., 1981).

Erickson et al. (1967) found that the application of asphalt to a sandy soil increased the yield of cucumber, cauliflower, potato, beans and rice by 14.4; 25.6; 32.7; 24.9 and 4.79 ton h^{-1} respectively in comparison with their yields in the same untreated soil which were 13.8; 24.3; 23.0; 18.7 and 0.4 ton h^{-1} respectively.

In a field experiment, 1.0 litre bituminous emulsion + 5.0 litre water per square metre, had a positive effect on the growth and yield of *Lycium enropeum* and *Atriplex numularia* plants in saline soil (De Waele, 1976a). In a none-saline soil, applications of 1.5 l m^{-2}bituminous emulsion seemed to have no effect on the growth of plants (mexican wheat, onion, carrot, celery, chervil, radish and tomato) (De Waele, 1976b).

In coarse volcanic soils from tropical regions treated with hydrophobic bituminous emulsions at rates 0.25 and 0.75 l m^{-2}, Lenvain and De Boodt (1976) reported that the yield of *Vetiveria zizanoides L.* increased by 30% in a greenhouse trial, and 43% in a field experiment.

A subsurface barrier 2 mm thick of asphalt at a depth of 60 cm of a loamy sand soil resulted on 100 percent increase in moisture and nitrogen retention. This led to an average increase in the production of pearl millet (*Pennisetum typhoides*) of 40 - 60 percent (Gupta and Aggarwal, 1980).

Al-Debagi (1983) found increases in the corn plant (*Zea mays L.*) dry weight shoots, roots, and the mean height of individual plant at all concentrations of bitumen treatments in both sandy clay loam and clayey soils. The effect was negative when both soils were treated with crude oil.

Kachinskiy et al. (1967) noticed that the use of large amounts of PAM; PAN; VAMA and some other polymers over 0.8 to 1.0% (on soils air-dry weight) were toxic to the micro-organisms and they inhibited plant growth.

Between May 1988 and June 1989 a series of greenhouse trials were established with four aims in mind:-

1. To assess the effect of the various treatments on the growth of *Eucalyptus spp.* and *Acacia spp.* plants and marram grass and lyme grass tillers grown in Druridge Bay dune sand.
2. The growth rate of *Eucalyptus spp.* plants (measured every two weeks).
3. The effect of various sand chemical stabilizers used as mulches on the sand temperature (including temperatures at the surface and at depths of 5 cm and 10 cm). Air temperature in the greenhouse (10 cm above the sand surface) was also measured. The results of this experiment have been reported in 5.1.3.
4. Any observations on the growing plants and the changes in the stability of the sand surfaces treated with different chemical stabilizers.

5.2.3.2 Materials and Methods

In these experiments, pots containing 8 kg sand were planted with *Eucalyptus spp.* and *Acacia spp.* plants and marram grass and lyme grass tillers. All pots were irrigated to saturation, then left for two days to reduce the sand moisture content to field capacity. The mean moisture contents from the surface were 15.89% and 16.12% on the oven-dry weights of the (*Eucalyptus spp.* and marram grass) and (*Acacia spp.* and lyme grass) experiments respectively. At these levels of moisture contents, chemical materials were then added to the sand surface of the pots containing the plants. A Falcon 10 litre sprayer (Cooper, Pegler and Co. Ltd) was used for the application of all chemicals except Aq1 and Aq2 which because of their short gelating time (c. 30 secs. and 20 minutes respectively), were added by pouring the solutions on to the sand surface. The plants were irrigated every three days and their height measured every 14 days for 82 days and then after 210 days. Soon after the experiment began it became obvious that measuring accurately the growth of the multi stemmed *Acacia spp.*, lyme grass and marram grass was impossible. Thus the Eucalyptus plants were the only ones

to be measured over the 210 day period, the other species were used only as a check on the possible toxicity of any of the treatments.

5.2.3.3 Results, Statistical Analysis and Discussions

The results of the bi-weekly measurement of *Eucalyptus spp.* growth rate over the 210 day experiment is presented in table 5.45. The increases percentage in plant height after 35; 77 and 205 days of cultivation is indicated in figure 5.59. All the percentages are on the bases of the individual plants height 5 days after the treatment with the various chemical materials.

The results show that, there was a continuous increase in the height of the *Eucalyptus spp.* with the time. The statistical analysis of the total increases in plant heights after 210 days from cultivation and under the effect of various chemical treatments (appendix table 5.29), indicated that, the differences between the various chemical treatments are insignificant, as Fcal. (1.26) is less than Ftab. (2.10) at 5% level of significance. The individual 95% CI's for the mean based on pooled standard deviation indicated that, although the Eucalyptus heights were increased under some chemical materials and decreased under the others in comparison with the control, none of these differences was significant. Therefore, no particular treatment has either any adverse or beneficial effect on Eucalyptus growth. This final result could be because of the original difference in plant height at the start of the experiment.

In conclusion, results of young *Eucalyptus spp.; Acacia spp.* plants and marram grass and lyme grass tillers experiments, can be summarized as following:

1. None of the chemical materials used had any toxic effects on the plants. For example, photos 5.27 - 5.32 show the growth of both *Eucalyptus microtheca* and marram grass tillers in Druridge Bay sand treated with F.E.; B.E. and Aq1. Photo 5.33 shows the growth of lyme grass tillers in samples treated with Aq2; whilst, the photo 5.34 shows the effect of all chemical treatments

Table 5.45: Effect of Various Chemical Stabilizers on the Height of *Eucalyptus microtheca* Plants.

Treats	Conc.*	Eucalyptus Height in (cm) After Days From Spraying							
		5	12	26	40	54	68	82	210
PVA1	0.2%	78.0	79.0	80.0	83.0	86.0	88.0	90.0	94.0
		119.0	119.0	120.0	122.0	126.0	127.0	127.0	128.0
PVA1	0.4%	85.0	85.0	85.5	87.0	89.0	90.5	93.0	107.0
		114.5	114.5	115.5	118.0	120.0	122.0	129.0	148.0
PVA2	0.2%	97.0	97.0	98.0	101.5	105.5	108.0	112.0	138.0
		117.0	118.0	122.0	126.5	131.0	134.0	137.0	150.0
PVA2	0.4%	90.0	90.0	95.0	99.5	105.0	108.0	110.0	118.0
		89.0	89.0	91.0	94.0	96.0	98.0	99.5	115.0
PEG3	0.2%	95.0	96.0	97.0	101.0	104.0	105.0	106.5	112.0
		112.0	115.0	123.0	131.0	137.0	143.0	147.5	151.0
PEG3	0.4%	111.0	111.0	113.0	115.0	120.5	123.0	124.5	130.0
		118.0	118.0	120.0	123.0	126.0	127.5	128.5	131.0
PEG4	0.2%	109.0	109.0	110.0	112.5	114.0	114.5	117.0	126.0
		95.0	96.5	99.0	102.0	106.0	108.5	113.5	127.0
PEG4	0.4%	96.5	98.0	100.5	104.5	109.0	111.0	115.0	127.0
		118.0	119.0	121.5	124.0	126.5	128.5	132.5	142.5
V1	0.05 l m^{-2}	105.0	105.0	106.0	108.0	110.0	111.5	114.0	145.0
		111.0	111.0	112.0	112.0	113.0	116.0	119.0	127.0
V1	0.10 l m^{-2}	93.0	93.0	95.0	97.5	99.0	101.0	104.0	120.0
		100.0	101.0	105.0	108.0	111.0	113.0	117.0	130.0
V2	0.05 l m^{-2}	129.0	130.0	132.0	134.0	138.0	142.5	147.5	161.0
		118.0	118.0	119.0	121.0	124.5	126.0	126.5	127.0
V2	0.10 l m^{-2}	127.0	128.0	131.0	134.0	137.0	140.0	145.5	156.0
		104.0	104.5	106.0	109.0	110.5	112.5	121.0	131.0
V3	0.05 l m^{-2}	83.0	83.5	84.0	88.0	89.0	89.5	90.0	104.0
		136.5	137.0	137.0	137.0	137.0	139.0	144.0	151.0
V3	0.10 l m^{-2}	119.5	119.5	119.5	120.5	121.0	121.0	121.0	128.0
		83.5	84.0	85.5	89.0	91.0	92.0	95.0	108.0
F.E.	0.2 l m^{-2}	136.0	136.0	139.0	141.5	143.0	145.0	145.0	152.0
		106.0	106.0	106.5	107.5	110.0	111.0	113.0	118.0
F.E.	0.4 l m^{-2}	147.5	148.0	149.5	153.0	160.0	164.0	167.0	173.0
		109.0	109.0	109.5	112.0	115.5	117.0	118.0	122.5
B.E.	0.5 l m^{-2}	108.5	109.0	112.0	114.5	116.0	117.5	118.5	124.0
		99.0	100.5	104.0	107.0	111.0	114.0	116.5	118.0
B.E.	1.0 l m^{-2}	120.5	121.5	121.5	121.5	123.0	124.0	125.0	128.0
		103.5	104.0	105.5	110.0	114.5	116.0	116.0	121.5
Aq1	0.33%	115.0	116.0	120.0	123.0	126.0	128.5	129.5	137.5
		110.0	112.0	118.0	123.0	128.5	132.0	136.0	140.0
Aq1	0.66%	81.5	83.0	85.0	88.5	92.0	94.0	97.0	103.0
		115.5	117.0	120.0	123.0	126.5	129.0	132.5	142.0
Control		89.0	89.0	89.0	89.0	90.0	92.5	95.0	108.5
		108.0	109.0	110.0	113.0	115.5	119.0	123.5	129.5

* All (%) are on the base of air-dry sand.

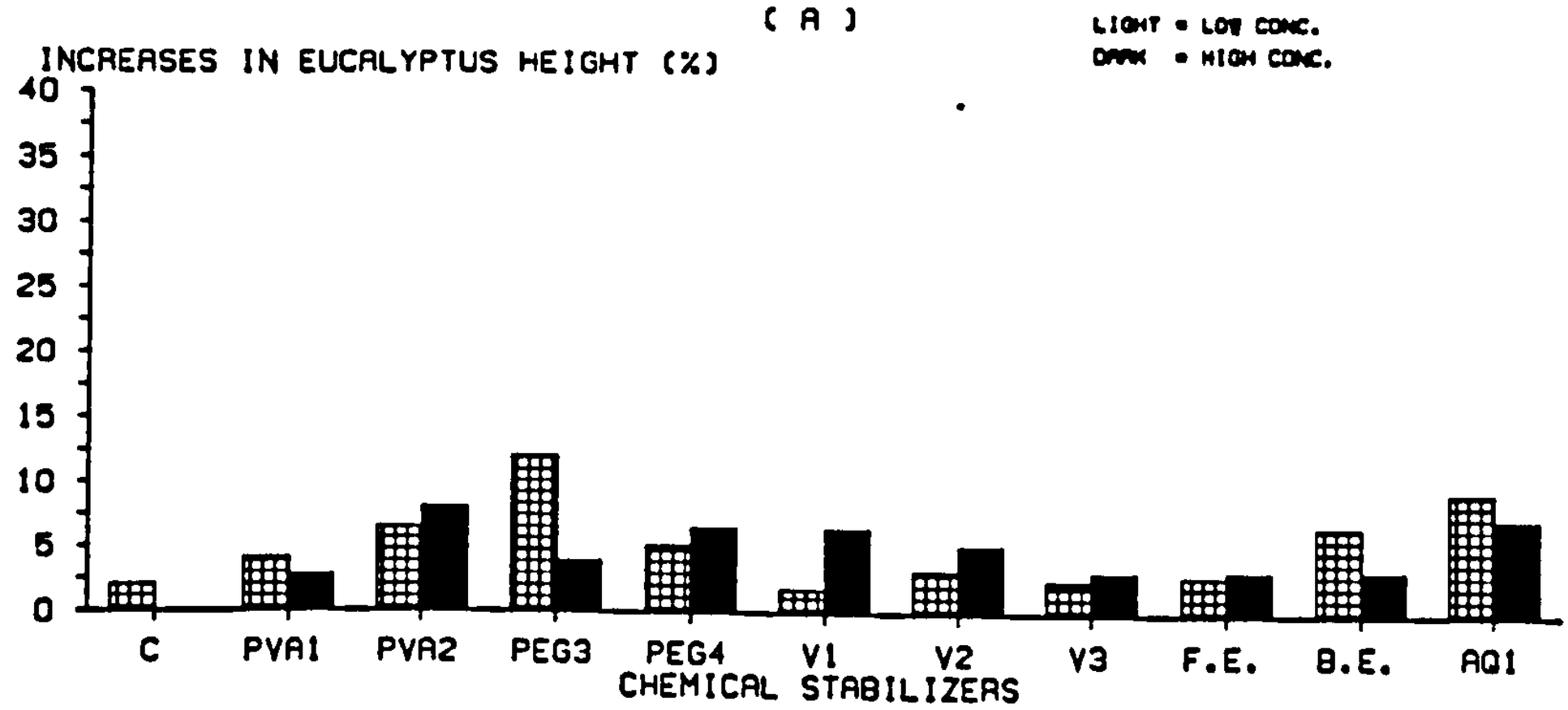


FIG. 5.59: INCREASES PERCENTAGE OF THE EUCALYPTUS PLANTS HEIGHT GROWN IN DRURIDGE BAY SAND IN: (A) 35 DAYS; (B) 77 DAYS; (C) 205 DAYS OF CULTIVATION.

used in this study on the growth of the *Acacia cyanophyla* plants. All photos 5.27 - 5.34 were taken 3 months after the treatments.

2. There was a continuous increase in all Eucalyptus and Acacia plants heights with the time.
3. Marram grass tillers in both treated and untreated sand produced seeds after about two months from cultivation.
4. Aq1 0.66% and B.E. 1.0 l m^{-2}followed by B.E. 0.5 l m^{-2}; Aq2 250 gm $m^{-2}$and F.E. 0.4 l $m^{-2}$and 0.2 l m^{-2}treated surfaces were the only ones to remain stable after 3 months from spraying. All other chemicals including: PVA1; PVA2; PEG3; PEG4; V1; V2 and V3 rapidly lost their stabilization characters, indicating that whilst they could be used as initial soil conditioners, they would not be very useful as sand dune stabilizers. This latest result is however contrary to the findings of much of the literature (see section 5.1.5.1).

Plates 5.27 & 5.28: Growth of *Eucalyptus microtheca* Plants in Druridge Bay Sand Samples Treated With F.E. and B.E. (3 Months After Planting).

Plate 5.29: Growth of *Eucalyptus microtheca* Plants in Druridge Bay Sand Samples Treated With Aq1 (3 Months After Planting).

Plate 5.30: Growth of Marram Grass Tillers in Druridge Bay Sand Samples Treated With F.E. (3 Months After Planting).

Plate 5.31: Growth of Marram Grass Tillers in Druridge Bay Sand Samples Treated With B.E. (3 Months After Planting).

Plate 5.32: Growth of Marram Grass Tillers in Druridge Bay Sand Samples Treated With Aq1 (3 Months After Planting).

Plate 5.33: Growth of Lyme Grass Tillers in Druridge Bay Sand Samples Treated With Aq2 (3 Months After Planting).

Plate 5.34: Growth of *Acacia cyanophyla* Plants in Druridge Bay Sand Samples Treated With Various Chemical Materials Under the Study (3 Months After Planting).

CHAPTER 6

SAND DUNES IN IRAQ

6.1 Introduction

In Iraq, desert lands comprise about two thirds of the total ground surface area of 436,000 km^2. The desert includes wide expanses of sand dunes, most of which are currently active (Buringh, 1960; and Mohammed, 1984). For example, in the centre, the total area of sand dunes around Baiji and Al-Aith regions is about 220,000 donums (Saleh, 1984), whilst, in the southern part of the country, sand dunes cover about 8,000,000 donums between the Euphrates and Algaraf rivers, and west of the Euphrates down to the city of Basra and the border between Iraq and Kuwait (Mohammed, 1984). Some pseudo-sand dunes are also found in Al-Massab Al-Aam and Al-Numania sand dunes fields (Hannah, 1984). Figure (6.1) illustrates location of sand dunes in Iraq (Dougrameji and Kaul, 1972).

Baiji sand dunes are generally coarser in texture than those of Al-Massab Al-Aam, and contain less salts and less alkaline earth carbonates. Added to that, the environmental conditions of the Baiji sand fields are much better than those of the southern sand dunes. They have more preciptation, lower mean annual air-temperatures and less water evaporation. Finally, it is worth mentioning that the Baiji sand dunes are protected to some extent by the Himrin mountains which control local windspeeds, and in turn wind erosion of these sand dunes.

Although Baiji sand differs from Druridge Bay sand, especially the clay contents and the exchangeable sodium percentages (ESP) (table 6.1a), the chemicals selected for field testing at Druridge Bay were also tested on the Baiji sands in both laboratory and greenhouse experiments. In addition to Aq1; Aq2; B.E. and F.E., PVA2 was also tested as this was considered to be the best of the remaining group of chemicals and its performance could have changed with the different properties of the Baiji sand.

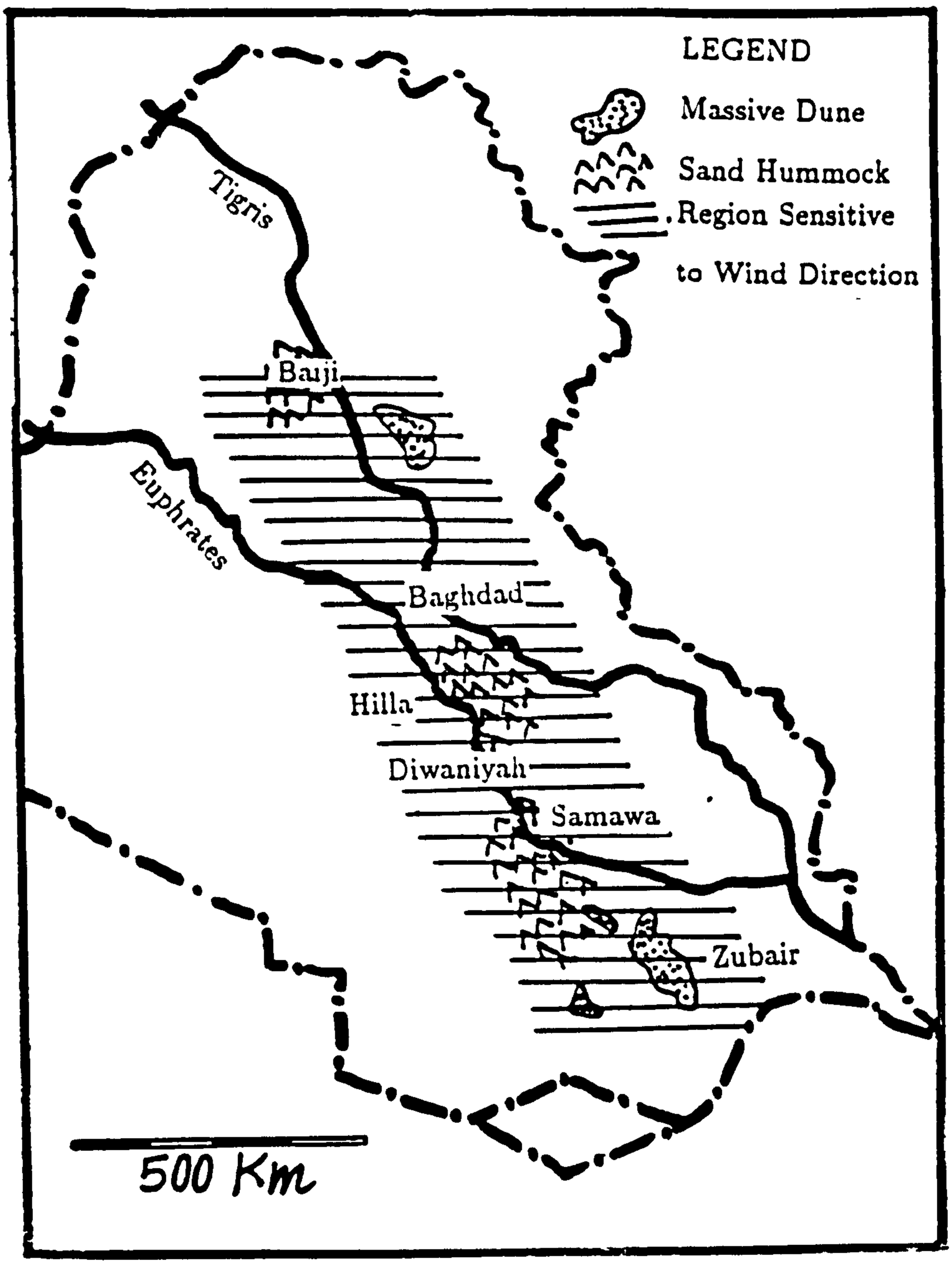


Figure 6.1: Location of Sand Dunes in Iraq

(After Dougrameji and Kaul, 1972).

Table 6.1a : Some Chemical and Physical Characteristics of Both Baiji and Druridge Bay Sand Dunes.

Character	Baiji Sands	Druridge Sands
EC (mmhos cm^{-1})	0.221	0.188
pH	7.4	7.2
Alkaline-Earth Carbonates (%)	10.46	6.37
Gypsum (meq per 100 gm soil)	1.49	0.99
Organic Matter (%)	0.088	0.83
Sand (Coarse; Medium and Fine) (%)	0.1; 16.5; 78.3	0.3; 84.6; 14.5
Silt (Coarse; Medium and Fine) (%)	1.9; 0.3; 0.4	0.3; 0.1; 0.1
Clay (%)	2.5	0.1
Texture	Sandy	Sandy
C.E.C. (meq per 100 gms soil)	3.40	0.71
Soluble Ions (meq per 100 gms soil)		
Na^{+}	0.018	0.037
K^{+}	0.020	0.011
Ca^{++}	0.157	0.127
Mg^{++}	0.020	0.017
Cl^{-}	0.020	0.042
$CO3^{--}$	0.000	0.000
$HCO3^{-}$	0.150	0.105
Total N (%)	0.013	0.019
Available P (mgm per 100 gm soil)	1.250	0.396
S.A.R.* (meq $l^{-1/2}$)	0.191	0.436
Exchangeable Cations (meq per 100 gms soil)		
Na^{+}	0.032	0.103
K^{+}	0.230	0.069
$Ca^{++} + Mg^{++}$	3.138	0.538
E.S.P.** (%)	0.941	14.507
Bulk Density (gm cm^{-3})	1.51	1.52
Sand Particles Density (gm cm^{-3})	2.68	2.64
Porosity (%)	44.00	42.00

* S.A.R. (Sodium Adsorption Ratio) = $Na^{+} / [(Ca^{++} + Mg^{++}) / 2]^{-1/2}$

Na^{+} ; Ca^{++} ; Mg^{++} = Soluble Cations (meq l^{-1})

** E.S.P. (Exchangeable Sodium Percent) = (Na^{+} / C.E.C.) x 100%

Na^{+} = Exchangeable Sodium (meq / 100 gm soil)

C.E.C. = Cation Exchange Capacity (meq / 100 gm soil)

6.2 The Origin of Iraqi Sand Dunes

Most of the material forming the Iraqi sand dunes is thought to be of local origin, possibly resulting from erosion of over exported soils (Al-Taie, 1984). Hannah (1984) believes that poor irrigation techniques associated with the lack of adequate drainage is responsible for much of the salinisation in the Central and Southern Plains. Consequently large areas are devoid of any vegetation cover and are hence susceptible to erosion. Therefore, winds remove the finer particles of clay and silt and leave behind the coarser particles of sand. In some circumstances the eroded fine sand - coarse silt fractions are deposited creating pseudo-sand dunes. These type of dunes are found in parts of the Al-Numania dune system (44% - 93% sand) and Al-Massab Al-Aam dune system (43% - 96% sand). Similar pseudo-sand dunes are also found in Algeria, Australia, and U.S.S.R. (Buringh and Edelman, 1955; and Buringh, 1960).

Mahmoud and Al-Ani (1985) working on Al-Najaf, Al-Samawa, and Al-Nasiriya sand dune sediments in the south-western parts of the Western Desert of Iraq, suggested that these three dune fields are formed from reworking of recent sediments of the Euphrates river and with some additional input from some older geological formations.

6.3 The Causes of Sand Dunes Formation in Iraq

Many factors are responsible for the formation and the extension of the sand dunes in Iraq. Some factors are ecological, while others can be attributed to the unwise human activities and use of natural resources, especially soil and water (photos 6.1 - 6.3).

Mohammed (1984) designates the following factors, as responsible for the formation of sand dunes in Iraq:

6.3.1 Weather Conditions: These include,

i. The mean annual precipitation rate in Iraqi sand dune regions is less than

Plate 6.1: Complete Destruction of Vegetation Cover and the Start of Sand Dune Formation in the South of Iraq.

Plate 6.2: Remnants of Few *Tamarix articulata* Plant Cover and the Development of the Sand Dune in the South of Iraq.

Plate 6.3: Grazing of Sparse Vegetation Cover in the West Desert of Iraq.

200 mm a year, and is limited largely to the winter months.

ii. High temperatures during most months of the year result in large soil moisture deficits.

iii. The high frequency of strong dry winds during summer season.

6.3.2 Soil Management: Which includes,

i. Overgrazing of the rangelands during most months of the year, especially spring time.

ii. The degradation and salinisation of soils as the direct result of poor irrigation practices. This is a particular problem in the Al-Massab Al-Aam sand dune systems in southern Iraq.

iii. Poor of cultivation techniques, related especially to the timing of cultivation and the implements used.

iv. The absence of conservation methods protecting the cultivated soils from wind erosion in most parts of the country, especially those planted with field crops and vegetables. It is important to mention that these soils remain without vegetation cover for a long period every year, especially during summer season.

6.3.3 Topography:

Wind erosion is more effective in open regions. With the expectation of the Baiji sand dunes which are protected to some extent by the Himrin mountain range, the remaining dune fields lack any such protection as they occur in extensive, slighty undulating plains.

6.3.4 Economic and Social Factors:

The migration of many farmers and villagers to the large cities in order to improve their standards of living, has resulted in extensive areas being abandened which, without cultivation makes them more exposed to salinization, wind erosion, and sand dune formation. This is very clear in many regions in the southern and the central parts of Iraq.

6.4 Problems Arising from the Movement of Sand Dunes in Iraq

As discussed previously in chapter two, the mobile sand dunes in Iraq cause much damage by inundating cultivated areas, blocking roads, canals and drains, and badly effecting public health. Photos 6.4 and 6.5 illustrate the blocking of two highways in the southern part of Iraq by the mobile sand dunes.

6.5 Previous Studies on Iraqi Sand Dunes

Many studies have been reported on various aspects of the geomorphology, sedimentology, mineralogy, ecology and the origin of sand dunes in Iraq eg. Al-Hilli (1970); Al-Saadi (1971); Skocek and Saadallah (1972); Al-Ani (1979); Buday

Plate 6.4: A Highway Blocked by Mobile Sand Dunes in the South of Iraq (Basra - Safwan).

Plate 6.5: Another Highway Blocked by Mobile Sand Dunes in the South of Iraq (Baghdad - Imarah).

(1980); Jawad Ali and Al-Ani (1983); Al-Ani and Haddad (1984); Al-Rawi (1984); Al-Taie (1984); Dougrameji (1984); Dthahi et al. (1984); Hannah (1984); Mahmoud and Al-Ani (1985); and Shaker (1985).

Mohammed (1984); Saleh (1984); and Hannah (1984) present information about methods of sand dune stabilization in Iraq and the effectiveness of these in relation to meteorological conditions. Previously, Al-Hilli (1970) investigated the frequency of various plant species within sand dunes in south Baiji. Herein, five main plant groups were distinguished, of which the following species were the most common ones: *Cyperus conglomeratus Rootb.; Onopordon canum Eig.; Lagonychium farctum (Banks et Soland.) Borr.; Alhagi maurorum Medic.* and *Astragalus spinosus (Forsk.) Hand. Mazz.* Meteorological factors, soil conditions, and other ecological conditions affecting plant growth in this area were also discussed. In another ecological study, Al-Ani and Haddad (1984) investigated the natural vegetation of some locations near Baiji. Fifty eight plant species were recorded on the sand dunes north and west of Baiji city. Some native species were identified which could possibly assist in the stabilization of the sand dunes. These are:-

- *Astragalus spinosa*
- *Artemisia scoparia*
- *Chrozophora tinctoria*
- *Convolvulus hamrinesis*
- *Cutandia dichotoma*
- *Cyperus conglomaratus*

In two papers presented at the "First Arab Seminar on Sand Dunes Fixation and Desertification Control" held in Baghdad from 14 to 22 October 1984, Abdul-Halim (1984) discussed the effect of soil salinization on soil desertification in Iraq. Ismael (1984) reported in his study of the effect of sand moisture content on windspeed over the surface that, windspeed over a wet sand surface was three

times as high as over a dry one. This is due to the high friction between the wind and the loose sand particles in the case of dry sand surface.

Before examining the stabilization techniques used, it will be useful to identify some of the soil characteristics and the meteorological conditions of the sand dune areas of Iraq.

6.6 Soil Characteristics and Weather Conditions of Sand Dunes in Iraq

Table 6.1b indicates some physical and chemical characteristics of some sand dunes and pseudo-sand dunes in Iraq.

Since the sand dunes in Baiji (center of Iraq) and Al-Massab Al-Aam (south of Iraq) regions form the main two groups of dunes in the country, attention will focus on the soil characteristics and weather conditions of these two dune fields. Much of the discussion that follows is derived from the work of Mohammed (1984).

6.6.1 Soil Characteristics

6.6.1.1 Baiji Sand Dunes:

The Baiji sand dunes, usually comprise at least 90% sand, with clay and silt particles together amounting to usually less than 10%. Quartz is the most available mineral, followed by alkaline earth carbonates, feldespars and sometimes gypsum, and pH is inevitably in excess of 7.0. Table 6.1b shows some physical and chemical characteristics of these sand dunes.

The coarse texture of the Baiji dunes offer a number of characteristics that can play an important role in the stabilization of these dunes:

i. Very slow migration of these dunes.

ii. Very high surface infiltration rate, which can lead to almost complete infiltration of precipitation into the dunes.

iii. lower water evaporation from the sand surface in comparison to the sand

Table 6.1b: Some Physical and Chemical Characteristics of Some Sand Dunes and Pseudo-Sand Dunes in Iraq (After Al-Taie, 1984).

Position	Mechanical Analysis				pH	E.C. mmhos cm^{-1}	Gypsum %	$CaCO_3$ %	O.M. %	General Description
	Sand %	Silt %	Clay %	Texture						
Deposition plain	28	26	26	sandy clayey loam	7.9	24	0.6	26	0.4	active barchan pseudo-sand dunes 1-sevral metres high
Sheik Saad (Dialah)	94	1	5	sandy	7.9	0.5	0.2	24	0.1	active barchan sand dunes 1-10 m high
Al-Muqdadia (Dialah)	94	2	4	sandy	7.9	0.6	0.1	43	0.1	active barchan sand dunes 1-10 m high
Jauf Al-Sakher	93	1	6	sandy	8.0	10	0.1	19	0.1	active barchan sand dunes 1-5 m high
Baiji	95	1	4	sandy	8.0	0.5	0.1	19	0.1	active barchan sand dunes 1-several metres high
Al-Aith	92	1	7	sandy	8.0	0.5	0.1	19	0.1	active barchan sand dunes 1-15 m high
South desert	94	1	5	sandy	8.2	1.6	0.2	12	0.1	sand dunes 1-15 m high, covered with some desertic shrub
Souk Al-Shiokh	80	5	15	sandy loam	7.9	46	0.9	26	0.7	active barchan pseudo-sand dunes 1-several metres high
East of Al-Samawa	93	4	3	sandy	8.3	3.5	1.3	11.8	0.1	semi fixed sand dunes 1-10m high, covered with some natural plants
Al-Massab Al-Aam*	43-96	0-34	4-23	loamy to sandy	8.1	2.8	—	23.5	0.3	active sand dunes and pseudo-sand dunes
Al-Numania*	44-94	0-36	6-19	loamy to sandy	7.9	4.0	3.4	—	0.2	active sand dunes and pseudo-sand dunes

* Data of Al-Massab Al-Aam and Al-Numania sand dunes and pseudo-sand dunes are after Mohammed (1984) and Hannah (1984), respectively.

dunes in Al-Massab Al-Aam region. This is due to the low capillary rise in Baiji sand profile. Lower water evaporation from Baiji sand dunes is responsible for the increase in water storage inside the dunes, which is very important for the success of deep cultivation and planting of *Tamarix articulata* cuttings.

6.6.1.2 Al-Massab Al-Aam Sand Dunes:

The texture of these sand dunes ranges between loamy and loamy sand. Consequently, these dunes can be called pseudo-sand dunes due to their high content of clay and silt particles. They also contain a high percentage of alkaline earth carbonates, with an inevitable low level of organic matters. Table 6.1b indicates some physical and chemical characteristics of these dunes. The medium texture of Al-Massab Al-Aam dunes makes these dunes less amenable to stabilization than the coarser Baiji dunes. This can be attributed to the following properties of the finer textured sands:

i. Infiltration rate is low, thus much run off occurs and hence soil moisture reserves are low and usually only in the surface layers. This is not helped by the high intensity nature of most of the rainfall in this area.

ii. With a higher clay and silt content, capillary rise and water evaporation tends to be greater than in the Baiji sand dunes.

6.6.2 The Weather Conditions

6.6.2.1 Baiji Sand Dunes:

The Baiji region lies at about 115 m above sea level. The average annual air-temperature is 22°C. The lowest monthly mean minimum temperature is in December (10°C), while the highest mean monthly maximum in July (35°C). The mean annual evaporation loss exceeds 2400 mm. The monthly and annual precipitation averages are illustrated in table (6.2).

Table 6.2: Monthly and Annual Precipitation Averages at Baiji Sand Dunes (After Mohammed, 1984).

Monthly Averages (mm)												Annual
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average (mm)
34.8	30.2	36.3	24.5	10.5	—	—	—	—	3.7	25.1	39.0	193.9

No accurate information either for wind speeds or direction or on the air-humidity is available. In general, the weather conditions in Baiji region are much better than those in Al-Massab Al-Aam region. For example, Baiji region receives more precipitation, has lower air-temperatures and consequently less water evaporation than Al-Massab Al-Aam region. Furthermore, the Baiji sand dunes are protected by the Himrin mountain range; whilst, no natural obstacles are protecting Al-Massab Al-Aam sand dunes from wind erosion.

6.6.2.2 Al-Massab Al-Aam Sand Dunes:

Due to the extremely large area of these dunes, the data for the period 1941-1982 from four meteorological stations representing the borders of Al-Massam Al-Aam region will be illustrated and discussed. The stations are located in the areas of Baghdad, Al-Hai, Al-Dewania, and Al-Nasiriya. The height of these stations above the sea level are respectively 34, 15, 20, and 3 m.

i. Air-temperature:

The mean annual air-temperatures in Baghdad, Al-Hai, Al-Diwaniya, and Al-Nasiriya are 22.6°C, 23.8°C, 23.3°C, and 24.2°C respectively. The coldest month is January when air-temperatures fall to 9.6°C, 11.0°C, 11.0°C, and 11.5°C respectively. The yearly averages of minimum temperatures were 8.5°C, 8.2°C, 8.3°C, and 7.2°C respectively, with occasional minima falling to below 0°C. The highest

mean temperatures are in July and August with July mean maxima of 51.5°C, 51.0°C, 51.7°C, and 51.5°C respectively. In such conditions, the temperature of the exposed soil surface can exceed 80°C, while the maximum air-temperature can reach > 60°C. The highest daily temperatures ranges occur in the summer. Table (6.3) indicates the monthly and annual average air temperatures at the four meteorological stations:

Table 6.3: Monthly and Annual Mean Air-Temperatures Averages (°C) in Baghdad, Al-Hai, Al-Diwaniya, and Al-Nasiriya Meteorological Stations (1941-1982).

Met. Station	Monthly Averages												Annual Averages		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual	Mean Min.	Mean Max.
Baghdad	9.6	12.1	16.3	21.8	28.1	32.6	34.7	34.0	30.5	24.2	16.5	10.8	22.6	8.5	51.5
Al-Hai	11.0	13.2	17.3	22.8	29.3	33.6	35.4	35.0	31.8	25.8	18.3	12.4	23.8	8.2	51.0
Al-Diwaniya	11.0	13.2	17.3	22.9	29.0	32.9	34.4	34.0	30.8	25.1	17.7	11.8	23.3	8.3	51.7
Al-Nasiriya	11.5	14.0	18.2	23.8	29.9	33.0	34.7	34.8	32.0	27.1	18.8	12.8	24.2	7.2	51.5

ii. Humidity:

The annual average of the absolute humidity ranges from 9.9 - 11.9 mb. The maximum absolute humidity is 11 - 15 mb in the summer season, while the minimun is 8.4 - 9.5 mb in January and February. The annual average relative humidity is low 44% - 47%, with the maximum 67% - 73% occurring in winter; in summer the mean daily relative humidity falls to 23% - 31%. This however conceals in summer, the diurnal contrast of 12% - 13% during the day, rising to 60% - 70% at night. Table (6.4) presents the monthly and annual averages of both absolute and relative humidity.

iii. Precipitation:

Precipitation ranges from 118 mm a year in the southern part of Al-Massab Al-Aam sand dunes fields to 147 mm in the northern sector. The annual amount of precipitation is very variable. For example, in Baghdad, in 1957 it was 336

mm, and only 72 mm in 1953. Only very rarely is there any precipitation in the summer season (June - September). Most of the precipitations falls in December-April period when the number of rain days range between 40 and 60. Table (6.5) shows the monthly and annual precipitation rates at the four stations.

Table 6.4: Monthly and Annual Humidity Averages in Baghdad, Al-Hai, Al-Diwaniya, and Al-Nasiriya Meteorological Stations (1941-1982).

Met. Station	Monthly Averages												Annual Averages
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Baghdad													
Abs. H.	8.5	8.6	9.3	11.0	11.5	10.6	11.8	12.2	11.3	10.7	10.3	9.2	10.4
Rel. H.	72.0	62.0	52.0	47.0	33.0	23.0	23.0	28.0	38.0	38.0	57.0	72.0	44.0
Al-Hai													
Abs. H.	9.5	9.5	11.0	13.0	13.3	12.7	14.0	13.8	12.6	12.1	11.4	10.2	11.9
Rel. H.	73.0	65.0	58.0	52.0	37.0	27.0	26.0	27.0	29.0	39.0	56.0	72.0	47.0
Al-Diwaniya													
Abs. H.	8.9	8.8	9.9	11.6	12.3	12.7	14.1	14.3	12.9	11.7	11.0	9.6	11.5
Re . H.	71.0	60.0	52.0	45.0	34.0	27.0	28.0	29.0	32.0	40.0	56.0	69.0	45.0
Al-Nasiriya													
Abs. H.	9.0	9.1	10.1	12.2	14.1	15.1	15.1	13.8	11.9	11.3	11.0	9.8	11.9
Rel. H.	67.0	59.0	49.0	44.0	36.0	31.0	28.0	27.0	27.0	35.0	53.0	66.0	44.0

* Abs. H. is absolute humidity (mbar), and Rel. H. is relative humidity (%).

Table 6.5: Monthly and Annual Precipitations Averages in Baghdad, Al-Hai, Al-Diwaniya, and Al-Nasiriya Meteorological Stations (1941-1982).

Met. Station	Monthly Averages (mm)												Annual Averages (mm)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Baghdad	26.4	26.1	25.4	19.7	6.9	0.1	—	—	0.2	3.1	15.2	24.2	147.3
Al-Hai	27.2	19.3	21.2	18.7	6.4	0.1	—	—	—	3.1	17.5	24.4	137.9
Al-Diwaniya	23.2	16.8	20.1	16.1	7.9	—	—	—	—	3.3	13.2	21.7	120.7
Al-Nasiriya	22.4	16.1	16.9	14.6	7.0	0.1	—	—	—	3.2	14.7	22.5	117.5

iv. Windspeed and Direction:

Dominant wind directions in the Al-Massab Al-Aam region are northerly, north westerly and westerly with mean annual windspeeds of 3.4 - 3.8 m sec^{-1}.

In the spring and summer seasons, the strongest winds come from the south, these are frequently gale force and laden with dust. The incidence of these gales is in the region of 45 - 50 days per year with a mean speed of 25 -36 m sec^{-1}. Tables (6.6 and 6.7) show both monthly and annual windspeeds averages, the highest windspeed in (m sec^{-1}), and the frequencies of wind directions at all four meteorological stations.

Table 6.6: Monthly and Annual Windspeed Averages at the Four Stations (1941-1982).

Met. Station	Monthly Averages (m sec^{-1})												Annual Averages	Max. Speeds
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Baghdad	2.8	3.2	3.5	3.5	3.6	4.2	4.6	4.0	3.3	2.7	2.5	6.5	3.4	36.0
Al-Hai	3.7	3.6	3.7	3.5	3.6	4.4	4.5	4.1	3.6	3.0	3.0	3.0	3.6	35.0
Al-Diwaniya	3.7	3.7	3.9	3.7	3.7	4.4	4.5	4.1	3.4	2.9	2.9	3.0	3.6	25.0
Al-Nasiriya	3.7	3.6	4.0	3.9	4.2	4.9	4.8	4.3	3.7	3.1	3.2	3.0	3.8	30.0

Table 6.7: Frequencies of Wind Direction at the Four Stations (1941-1982).

Met. Station	Frequencies of Wind Direction							
	N	NE	E	SE	S	SW	W	NW
Baghdad	16.0	4.6	5.9	8.5	4.6	2.6	11.1	32.4
Al-Hai	9.2	2.3	10.6	4.6	3.3	1.7	28.7	26.7
Al-Diwaniya	23.1	3.4	7.8	5.5	3.2	2.5	27.0	15.0
Al-Nasiriya	12.9	2.7	8.0	8.9	4.6	3.0	19.9	33.0

v. Evaporation:

Due to the high temperatures, dry winds and the low relative humidities prevailing at most times of the year, water evaporation is extremely high. Table (6.8) presents both monthly and annual evaporation rates in (mm) for the period 1971-1980.

Table 6.8: Mean Monthly and Mean Annual Evaporation Rates at Baghdad, Al-Hai, Al-Diwaniya, and Al-Nasiriya Meteorological Stations (1941-1982).

Met. Station	Monthly Averages (mm)												Annual Averages
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Baghdad	71.3	107.0	193.3	279.5	419.5	566.7	628.8	564.9	413.7	255.4	143.5	62.3	3705.9
Al-Hai	95.3	126.1	223.7	356.2	485.5	670.8	715.3	671.6	559.9	339.6	173.0	98.3	4515.3
Al-Diwaniya	84.7	119.8	195.3	278.7	389.8	596.0	597.0	530.4	407.2	277.0	148.4	89.4	3713.8
Al-Nasiriya	72.3	99.2	178.8	255.6	357.7	481.5	539.9	514.2	390.4	249.0	136.0	80.0	3354.6

6.7 Methods Used for Sand Dunes Stabilization in Iraq:

As previously mentioned, two main groups of active sand dunes occur in Iraq, namely the Baiji and the Al-Massab Al-Aam systems. Mohammed (1984) has produced a comprehensive review of the techniques used in attempting to stabilize the dune systems.

6.7.1 The Stabilization of Baiji Sand Dunes:

Sand dune stabilization experiments in Baiji began in 1974. Although the results of these initial studies indicated some potentially useful methods of stabilization. The design of the experiments failed to allow for accurate measurement and analysis of the results, nevertheless the effectiveness of various approaches can be summarised as follows:-

6.7.1.1 Mechanical Methods:

As overgrazing was identified as one of the major causes of the destruction of plant cover which in turn increased erosion, the first attempts at stabilization of the dunes involved controlling grazing by the construction of fences. Where livestock were excluded from an area for two years it was found that plant cover increased by between 20 - 80% in the inter-dune area and by between 10 - 50% on the dunes themselves. Fencing is also used to prevent sand movement, in Baiji,

30 - 40 cm long branches of *Artemisia scopari* and *Phramitis commumis* are used in the construction of fences of chess design plots of 3 x 3 m or 4 x 4 m. Date fronds are more effective and thus the plot area can be increased to 5 x 5 m to 8 x 8 m. Although the effectiveness of this method on sand dunes stabilization was very clear. The cost in terms of labour input make it practicable only on a small scale.

6.7.1.2 Chemical Materials:

Curasol is the only chemical material used as a surface stabilizer for the drifting of sand dunes in Baiji. Although it successfully stabilized the sand for 2-3 years before decomposing, it reduced the growth and hence density of the natural vegetation. For this reason, together with it's high cost, the use of Curasol to be abandened.

6.7.1.3 The Growing of Plants and the Direct Afforestration of Sand Dunes:

Saleh (1984) refers to the success of growing pomegranate, olives, beans, watermelon, and carrot in Baiji sand dunes under irrigation. Water from Tigris river was used for the first two plants, while well water (EC = 4 mmhos cm^{-1}) was used for the other three (photo 6.6).

In another experiment on Baiji sand dunes, good results were obtained by planting *Acacia cyanophylla, Tamarix articulata, Eucalyptus microthica,* and *Casuarina species*; however, some plants failed to grow (photos 6.7 - 6.9).

Mechanical fences made of the dry branches of other plants were used for the protection of the young plants. Although all species were successfully established where irrigation was possible during the first two years, only *Tamarix articulata* cuttings were able to survive without any irrigation. The Tamarix cuttings needed to be partially immersed in water for two days prior to being inserted in the sand

Plate 6.6: The Use of Well Water for the Plantation of the Sand Dunes at Baiji (August 1988).

Plate 6.7: Successful *Eucalyptus microtheca* Plants on Baiji Sand Dunes (August 1988).

Plate 6.8: Successful *Tamarix articulata* Young Plants on Baiji Sand Dunes (August 1988).

Plate 6.9: Failure of Some *Tamarix articulata* Young Plants on Baiji Sand Dunes (August 1988).

to depths of 120 - 150 cm. This partial immersion of the cuttings in water before planting is very important for the immediate formation of roots. After some further tests on Tamarix cuttings, Saleh (1984) found that protective fencing was not required. However, he suggested that any failed cuttings should be replaced with new ones in the next year.

6.7.2 The Stabilization of Al-Massab Al-Aam Sand Dunes:

The stabilization of these dunes is vital if the Al-Massab Al-Aam project is to be successful. The Al-Massab Al-Aam project is a large storage reservoir for the drainage water coming from about 6,000,000 donums of saline soils. The reservoir is situated between the Tigris and Euphrates, and is connected with the Arabian Gulf (figure 6.2). Protection is required as it is situated to the east and south east of 4,000,000 donums of moving sand dunes, whose dominant direction of the movement is from the north west to the south east.

The basic methods used in the stabilization of Al-Massab Al-Aam sand dunes are:

6.7.2.1 Fencing:

This method, is not widely applicable in the stabilization of Al-Massab Al-Aam dunes since the area to be stabilized is very large and there are only limited supplies of suitable materials available.

6.7.2.2 Covering the Surface by Heavy Soils:

In this method, bulldozers were used to cover the surface of the moving sand dunes with a 25 - 40 cm layer of clayey soil. The clayey soil was carried from the nearest available source, and working at a rate of 2 donums per day per bulldozer, several thousands of donums of sand dunes have been stabilized successfully by this method. Lack of suitable heavy soil has however limited the applicability of this approach.

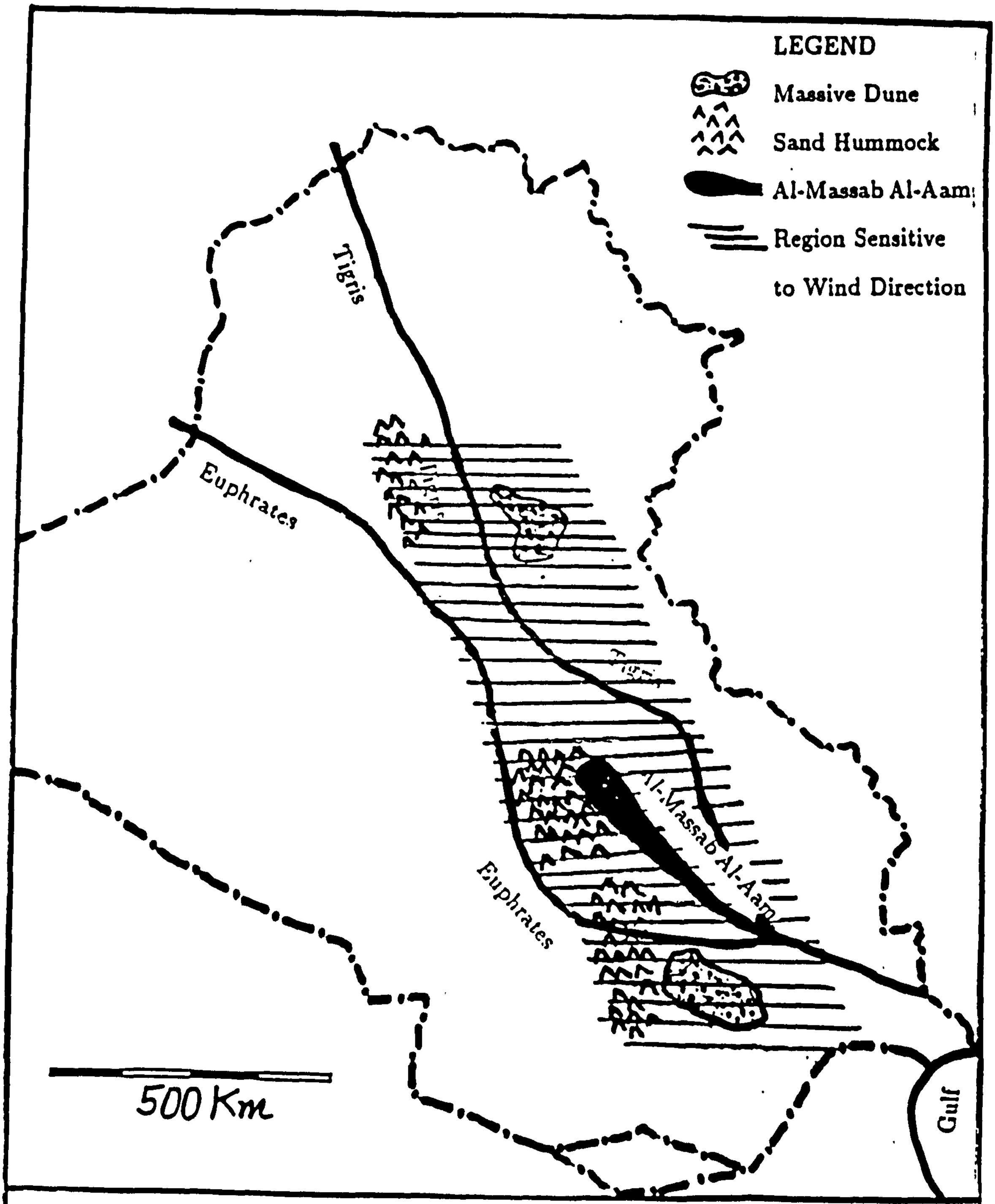


Figure 6.2: Map of Iraq and the Position of Al-Massab Al-Aam Reservoir and Sand Dunes.

6.7.2.3 Construction of Soil Dams:

This method had been previously used in many other countries through the building-up of large amounts of soil from the nearby areas as an obstruction in front of the mobile dunes fields. The main problem inherent in the use of this method is that great efforts are required. For example, to establish a soil dam of 100 m length, 4 m high and 0.1 slope, needs 1600 m^3 of soil. Nevertheless, this method has been widely used in Al-Massab Al-Aam region for the following reasons:

1) No better alternative was found to solve the problem of the drifting sands in this region.
2) The immediate availabiling of the necessary equipment (bulldozers) in the region at the start of sand dunes stabilization project, as they had previously been used for the construction of the Al-Massab Al-Aam reservoir.
3) This method was found to be very effective in sand dune stabilization, and gave a good chance for the young plants to grow on the soils behind the dam.
4) It was found that the surface of the soil dams were ideal for colonisation by natural plant seeds which were trapped by these dams.

6.7.2.4 Chemical Stabilizers:

Various chemicals, including rubber, "flint coat", urea, formaldehyde with water and dionoid materials, were tested but did not provide satisfactory stabilization of the dunes.

In 1979 an oil extract called "Atriat" (oil surplus product from Al-Dowrah oil refinery) and four mixtures from "Atriat" and "white oil" were applied at various rates to dunes near Al-Fajir town, only "Atriat" proved a suitable long term stabilizer (Al-Rawi, 1984); however, it is not permanent and needed replacing after 3 - 4 years. It has a major disadvantage in that it does not allow for plant growth.

Thus it is important to carry out some more tests on the effect of various soil chemical conditioners on the stabilization of Iraqi sand dunes, especially combination tests between chemical stabilizers and the establishment of plants as permanent stabilizers for the drifting sand dunes. The number of stabilizers used in the following trials was reduced from those used in the Druridge Bay sand experiments, since section 5.1.5 showed that several of the chemicals lacked long term stability. Thus the stabilizers used were restricted to PVA2; F.E.; B.E.; Aq1 and as available Aq2.

6.8 Effect of Various Chemical Stabilizers on Seed Germination

6.8.1 Techniques, Materials and Methods

In a greenhouse experiment carried out from 10th August 1988 to 10th September 1988, a procedure similar to that previously described in chapter 5 section 5.2.3.1 was followed on 300 gms of air-dry sand from Baiji. With the sand at field capacity (27.0% moisture on the air-dry sand weight), *Panicum spp.; Merlinda spp.; Melion spp.* and marram grass (*Ammophelia arenaria*) were sown and the following stabilizers applied: PVA2 (0.2% and 0.4%); F.E. (0.2 and 0.4 l m^{-2}); B.E. (0.5 and 1.0 l m^{-2}) and Aq1 (0.33% and 0.66%).

Due to Iraq's hot weather in summer (> 30°C), the moisture content of all samples, during the growing period, was maintained by adding 20 ml of water to each pot twice a day. The number of germinations per pot were counted every three days for a period of three weeks from sowing.

6.8.2 Results, Statistical Analysis and Discussions

Tables (6.9 - 6.12) and figures (6.3 - 6.6) illustrate number of germinations per pot and germination percentages of *Panicum spp.; Merlinda spp; Melion spp.* and marram grass seeds.

From the results it is obvious that both the type and concentration of stabilizer influenced germination rates of the four species studied.

The data for the Panicum germination tests shows that only Aq1 (0.33% and 0.66%) and F.E. (0.2 l m^{-2}) had no limiting effect on successful germination. All other treatments had lower mean germination rates than the control, generally it is the higher concentrations of stabilizer which causes greatest decline in germination, this effect is particularly marked for F.E. (0.4 l m^{-2}). In all but one replicate germination percentage does not change after 18 days.

Merlinda spp. is far less affected by the stabilizers than *Panicum spp.* After

Table 6.9: Effect of Various Chemical Stabilizers on the Number of *Panicum spp.* Germinations Per Pot.

Treats	Conc.*	Number of Germinations After Days From Cultivation						
		3	6	9	12	15	18	21
PVA2	0.2%	0	0	0	1	1	1	1
		0	0	3	3	3	3	3
		0	0	2	2	3	3	4
PVA2	0.4%	0	0	2	3	3	3	3
		0	1	3	3	3	3	3
		0	0	0	0	1	1	1
F.E.	0.2 l m^{-2}	0	0	1	1	2	2	2
		0	0	2	3	5	6	6
		0	0	1	1	1	1	1
F.E.	0.4 l m^{-2}	0	0	1	1	1	1	1
		0	0	0	0	0	0	0
		0	0	1	1	2	2	2
B.E.	0.5 l m^{-2}	0	0	4	4	4	4	4
		0	0	0	1	1	1	1
		0	0	2	2	2	2	2
B.E.	1.0 l m^{-2}	0	0	1	1	1	1	1
		0	0	4	4	4	4	4
		0	1	1	1	1	1	1
Aq1	0.33%	0	0	3	4	4	4	4
		0	2	6	6	6	7	7
		0	0	2	3	3	3	3
Aq1	0.66%	0	0	3	3	3	3	3
		0	0	4	5	5	5	5
		0	0	2	2	2	2	2
Control		0	0	3	3	4	4	4
		0	1	3	3	3	3	3
		0	0	1	2	2	2	2

* All (%) are on the base of air-dry sand.

Table 6.10: Effect of Various Chemical Stabilizers on the Number of *Merlinda spp.* Germinations Per Pot.

Treats	Conc.*	Number of Germinations After Days From Cultivation						
		3	6	9	12	15	18	21
PVA2	0.2%	0	10	16	18	18	18	18
		0	8	16	16	16	16	16
		0	6	19	21	21	21	21
PVA2	0.4%	0	7	16	16	16	16	16
		0	8	18	19	19	20	21
		0	4	11	11	11	11	11
F.E.	0.2 l m^{-2}	0	7	12	13	13	13	14
		0	5	11	15	15	16	16
		0	4	10	12	12	12	12
F.E.	0.4 l m^{-2}	0	2	5	7	7	7	7
		0	4	4	4	4	4	4
		0	2	2	2	2	2	2
B.E.	0.5 l m^{-2}	0	7	8	10	12	12	12
		0	7	11	11	11	11	11
		0	5	10	10	11	11	11
B.E.	1.0 l m^{-2}	0	2	5	5	6	6	6
		0	3	6	7	8	8	8
		0	4	6	8	8	8	8
Aq1	0.33%	0	14	21	21	22	22	22
		0	10	20	20	21	21	21
		0	12	18	21	21	21	21
Aq1	0.66%	0	8	18	19	20	20	20
		0	12	17	18	18	19	19
		0	9	16	17	17	18	18
Control		0	10	16	19	19	19	19
		0	8	18	19	19	19	19
		0	8	14	14	16	16	16

* All (%) are on the base of air-dry sand.

Table 6.11: Effect of Various Chemical Stabilizers on the Number of *Melion spp.* Germinations Per Pot.

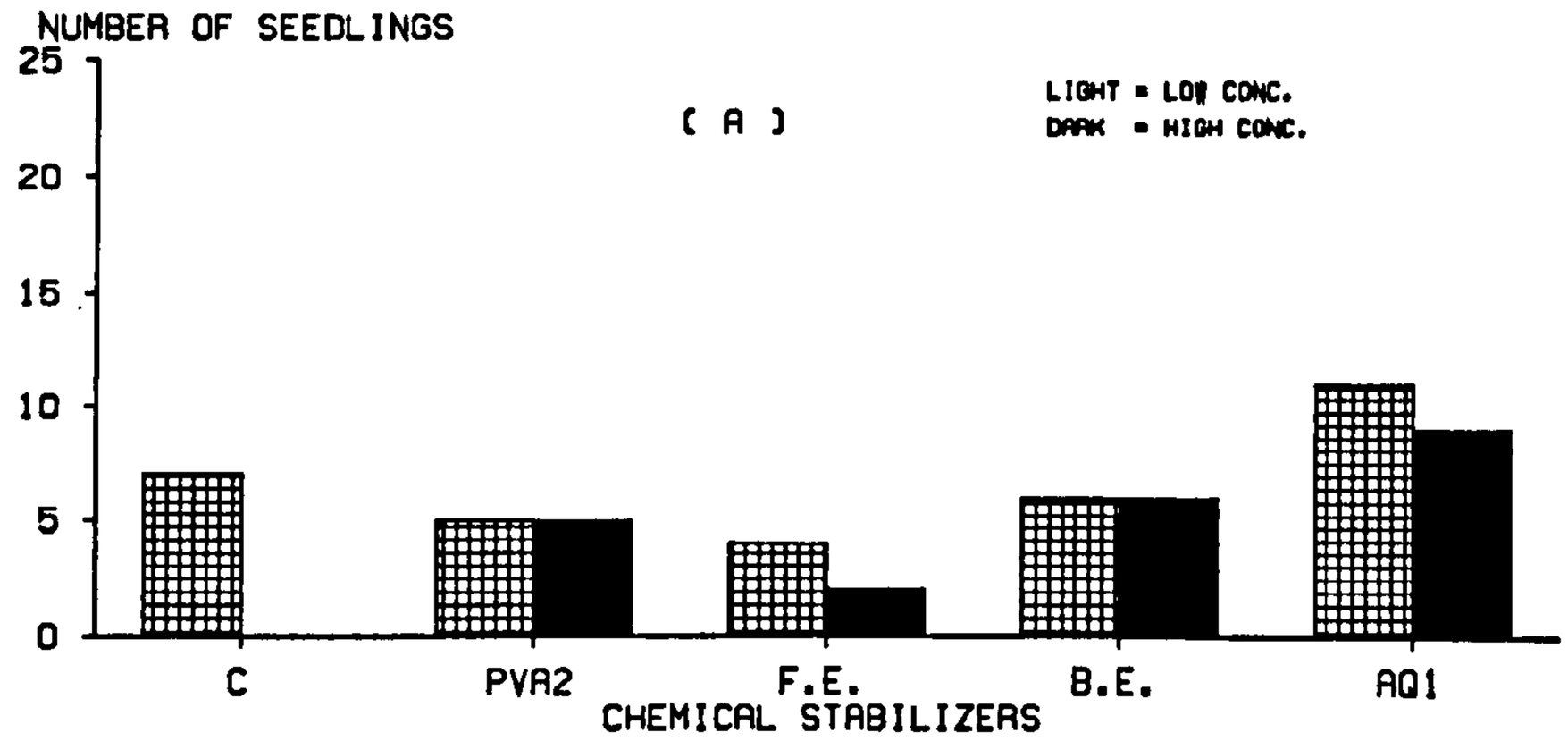
Treats	Conc.*	Number of Germinations After Days From Cultivation						
		3	6	9	12	15	18	21
PVA2	0.2%	0	14	21	21	21	21	22
		0	10	21	21	21	22	23
		0	12	22	22	22	22	22
PVA2	0.4%	0	7	15	15	15	17	21
		0	7	17	17	17	21	21
		0	6	18	18	18	21	22
F.E.	0.2 l m^{-2}	0	4	14	19	19	19	21
		0	5	15	16	17	17	17
		0	7	12	14	14	14	14
F.E.	0.4 l m^{-2}	0	6	6	6	7	7	8
		0	3	5	8	8	8	8
		0	3	3	6	6	6	6
B.E.	0.5 l m^{-2}	0	4	12	15	15	15	15
		0	7	11	11	12	12	12
		0	2	5	8	11	11	11
B.E.	1.0 l m^{-2}	0	4	6	7	7	7	7
		0	4	6	9	9	9	9
		0	4	6	8	8	8	8
Aq1	0.33%	0	21	23	24	24	24	25
		0	17	17	19	21	21	21
		0	17	21	23	23	23	23
Aq1	0.66%	0	12	17	17	17	17	20
		0	15	20	21	21	21	21
		0	10	18	18	18	20	23
Control		0	8	17	17	17	17	17
		0	6	14	16	16	17	17
		0	10	18	20	20	20	20

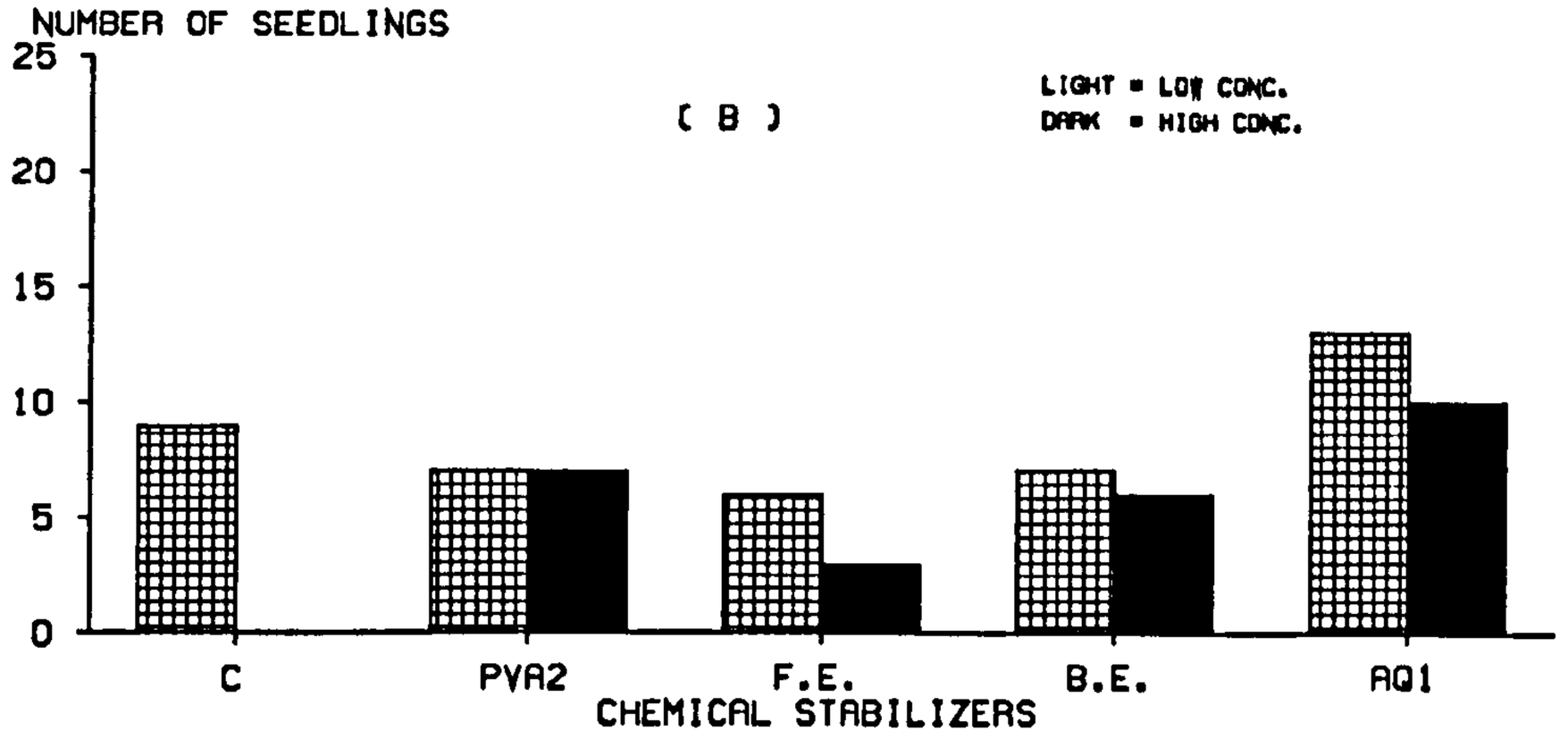
* All (%) are on the base of air-dry sand.

Table 6.12: Effect of Various Chemical Stabilizers on the Number of Marram Grass Germinations Per Pot.

Treats	Conc.*	Number of Germinations After Days From Cultivation						
		3	6	9	12	15	18	21
PVA2	0.2%	0	0	6	13	15	15	15
		0	0	4	13	13	14	14
		0	0	5	16	17	17	17
PVA2	0.4%	0	0	3	12	12	12	12
		0	0	2	10	11	11	11
		0	0	4	11	11	12	12
F.E.	0.2 l m^{-2}	0	0	2	10	10	10	10
		0	0	2	9	9	10	10
		0	0	4	11	11	13	13
F.E.	0.4 l m^{-2}	0	0	0	4	4	4	4
		0	0	1	5	6	6	6
		0	0	0	4	4	4	4
B.E.	0.5 l m^{-2}	0	0	2	10	10	10	10
		0	0	0	7	7	8	8
		0	0	1	9	9	10	10
B.E.	1.0 l m^{-2}	0	0	1	7	7	7	7
		0	0	0	5	5	5	5
		0	0	0	4	4	5	5
Aq1	0.33%	0	0	8	16	18	18	18
		0	0	5	17	17	17	17
		0	0	6	19	20	20	20
Aq1	0.66%	0	0	6	16	16	16	16
		0	0	1	11	11	12	12
		0	0	5	16	16	18	18
Control		0	0	5	15	16	16	16
		0	0	4	14	14	16	16
		0	0	3	13	13	13	13

* All (%) are on the base of air-dry sand.





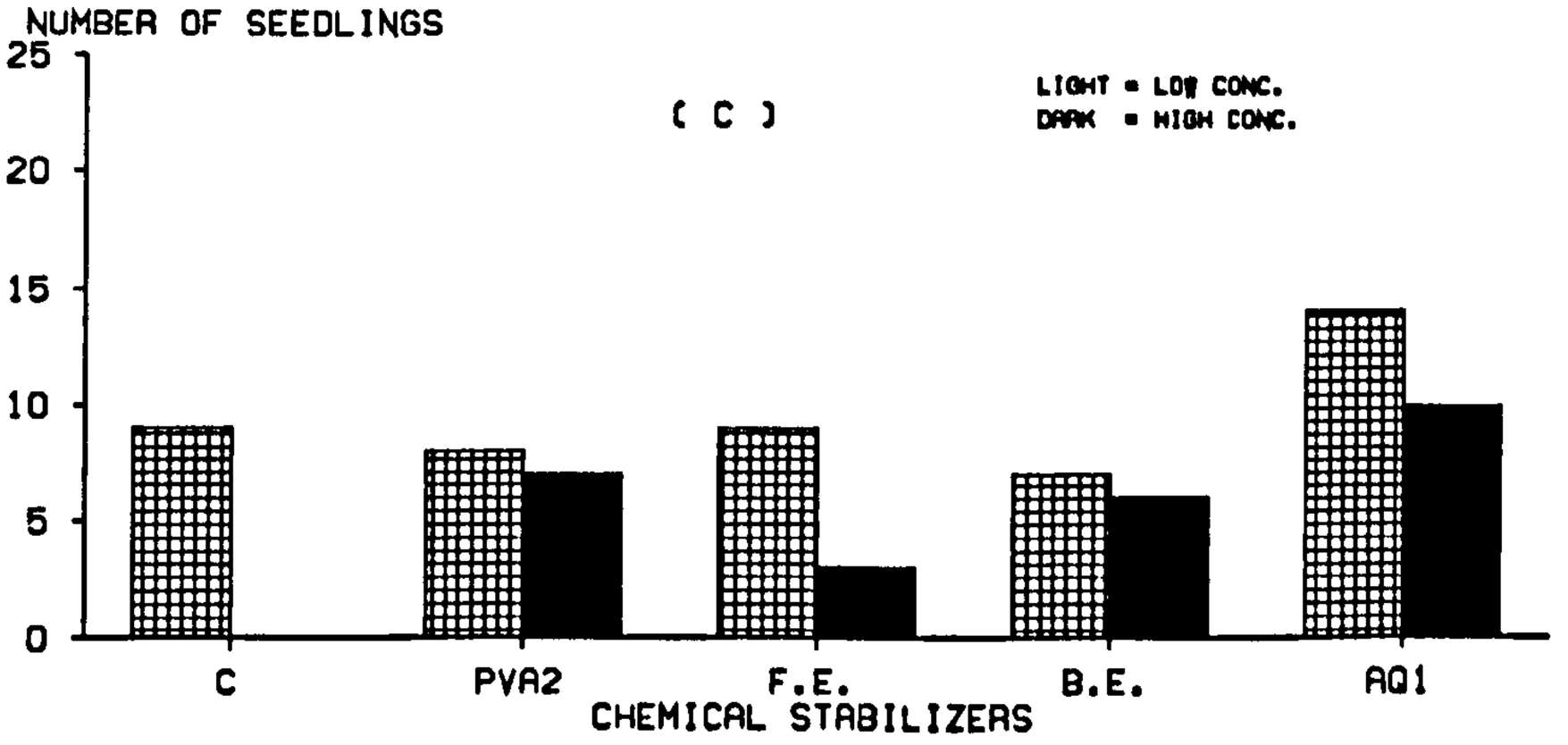


FIG. 6.3: TOTAL NUMBER OF PANICUM SPP. SEEDLINGS AFTER (A): 9 DAYS; (B): 15 DAYS; (C): 21 DAYS OF PLANTING IN BAIJI SAND AS AFFECTED BY VARIOUS CONDITIONER/TREATMENTS

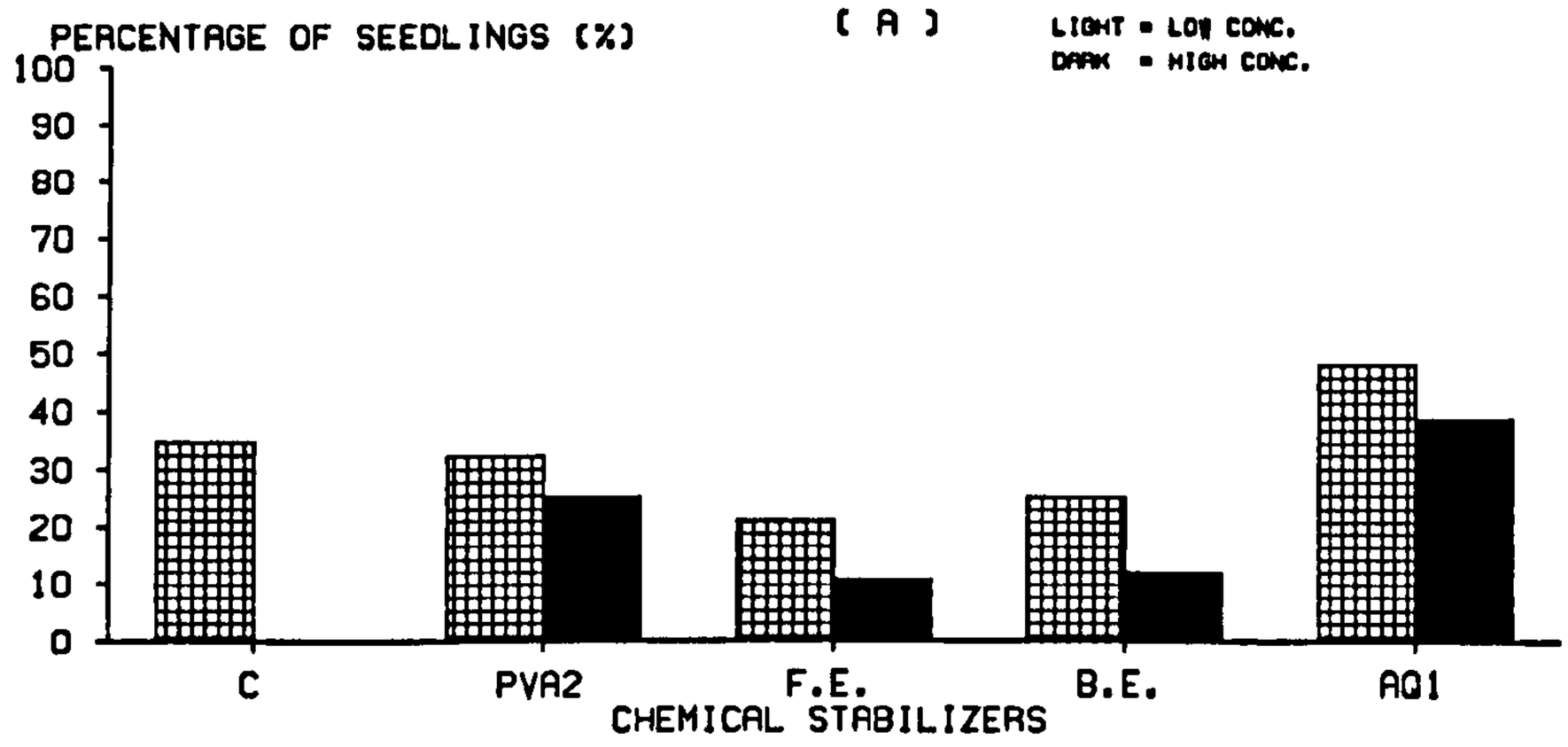


FIG. 6.4: PERCENTAGE OF MERLINDA SPP. SEEDLINGS AFTER (A): 6 DAYS; (B): 15 DAYS; (C): 21 DAYS OF PLANTING IN BAIJI SAND AS AFFECTED BY VARIOUS CONDITIONERS TREATMENTS

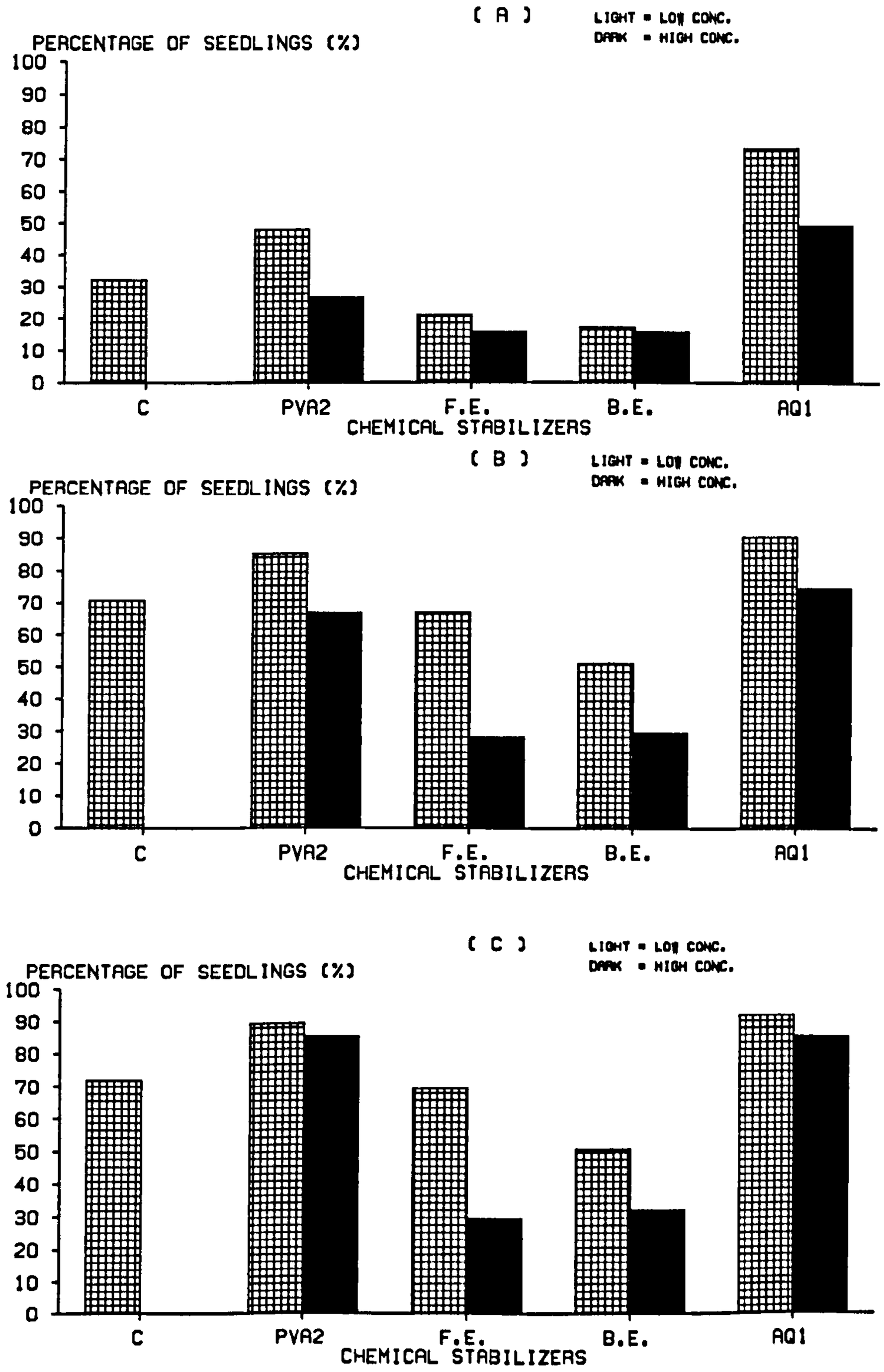


FIG. 6.5: PERCENTAGE OF MELION SPP. SEEDLINGS AFTER (A): 6 DAYS; (B): 15 DAYS; (C): 21 DAYS OF PLANTING IN BAIJI SAND AS AFFECTED BY VARIOUS CONDITIONERS TREATMENTS

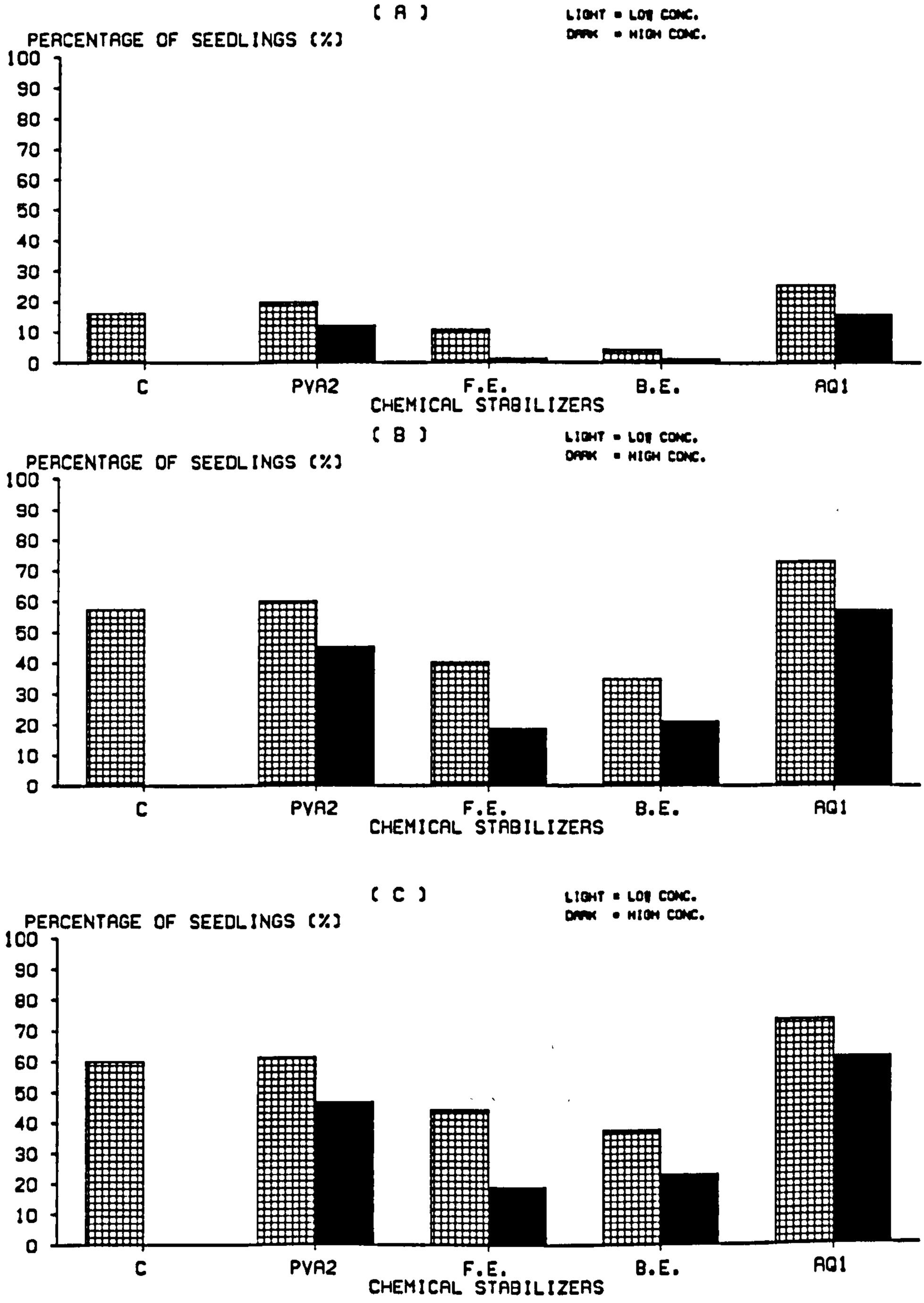


FIG. 6.6: PERCENTAGE OF MARRAM GRASS SEEDLINGS AFTER (A): 9 DAYS; (B): 15 DAYS; (C): 21 DAYS OF PLANTING IN BAIJI SAND AS AFFECTED BY VARIOUS CONDITIONER TREATMENTS

21 days most treatments average close to the control mean. The exceptions are the higher concentrations of PVA2 and both concentrations of F.E. and B.E. The higher concentration of both of these latter stabilizers cause a severe depression of the percentage germination. PVA2 (0.2 %) and especially both concentrations of Aq1 enhance germination rates.

The overall germination rates of *Melion spp.* are higher than those of *Merlinda spp.* The effect of the various stabilizers is however identical. PVA2 (0.4%), both F.E. and both B.E. treatments result in lower germination rates, whilst PVA2 (0.2%) and both Aq1 concentrations produce enhanced germination rates. There is little improvement in germination rates after 18 days.

Marram grass (*Ammophelia arenaria*) germination rates are also higher than *Panicum spp.* but are lower than both the rye grass species. Once again however the same stabilizers cause reduced germination success [i.e. PVA2 (0.4%) and both concentrations of F.E. and B.E., though it is the higher concentrations of these latter two which cause the greatest depression in rates]. Similarly PVA2 (0.2%) and both Aq1 concentrations produce enhanced germination rates. There is no change in germination rates after 18 days.

The causes of the variation in germination rates for the different species is difficult to determine. *Panicum spp.* is the least successful species and therefore if germination is difficult in the control samples then even the slightest adverse effect of the stabilizers will result in poor germination. The cause of decreased germination under most treatments is not known, it was not however a problem of seedlings being unable to penetrate the 'chemical crust'. The seeds of both rye grass species and marram grass germinated more successfully, (control rates 18/25 for both rye grasses and 15/25 for marram grass). As with *Panicum spp.* there was no obvious reason for the reduced germination rates of both *Merlinda spp.* and *Melion spp.*, however the reduced success of marram grass germination appeared to be related to the seedlings being unable to break through the 'surface

crust's' produced by some of the stabilizers.

In conclusion the following points can be made:-

1. *Panicum spp.* is not a successful species to grow in these sands.
2. Of the chemical stabilizers used Aq1 in both concentrations is the most successful, as it enhances germination rates of all 4 species tested. Following Aq1, PVA2 (0.2%) is the only other treatment that enhances germination rate, but only on 3 of the 4 species tested.
3. Both B.E. treatments and F.E. treatments cause the greatest reduction in germination success, the higher concentrations of these are especially detrimental.
4. For all stabilizers and all plants it is the higher of the two concentrations used that causes the greatest decrease in germination success.

6.9 Effect of Soil Chemical Stabilizers on the Soil Temperature

6.9.1 Techniques, Materials and Methods

The stabilizers PVA2 (0.2% and 0.4%); F.E. (0.2 and 0.4 l m^{-2}); B.E. (0.5 and 1.0 l m^{-2}) and Aq1 (0.33% and 0.66%) were applied to the surface of 2 kg air-dry Baiji sand contained in plant pots. Each treatment and the control had three replicates. By means of a mercury thermometer the temperature of the samples was recorded at the surface, at 5 cm and at 10 cm depths. In order to prevent the side effect of sun strike, the pots were well surounded with a layer of polystyrene. The temperatures were first measured 48 hours after treatment, and then every 24 hours for five days. All measurements were taken at noon.

6.9.2 Results and Discussions

The air-temperature, and the temperature of the sand samples for the five days of the experiment are listed in tables 6.13 - 6.15 and summarised in graphed

in figures 6.7 - 6.9.

As in the case of the Druridge Bay sand (chapter 5 section 5.1.3.3), it is obvious that the temperatures of the samples are directly related to the ambient air-temperature, with the sand temperatures fluctuating with air-temperature.

The surface temperatures for the sand mulched with all chemical stabilizers except the PVA2 treatments, exceeded the control surface temperature by at least 1°C (table 6.13). They are almost the same or slightly higher than the control in the case of both PVA2 concentrations. At 5 cm depth (table 6.14), the temperatures under all chemical treatments except PVA2, again exceeded the control often by more than 1 °C, especially when the air-temperature was very high (> 30°C). At 10 cm depth (table 6.15), sand temperatures under six of the eight chemical treatments are close to the control, the exception is the bitumen emulsion mulches (0.5 and 1.0 l m^{-2}), which on average exceeded the control by 0.8°C and 1.1°C respectively.

The sand surfaces treated with F.E.; B.E. and Aq1 exceeded air-temperatures, whilst PVA2 treatments and the control were slightly less. Thus certain treatments act to increase surface temperature which could have adverse effects on the water balance of the treated sands.

Figure (6.10) illustrates the effect of various chemical materials on the mean temperatures of the samples at the surface, 5 cm and 10 cm depths. The low and high concentrations refer to the chemicals concentration mentioned above. In the control the "light" blocks represent the air-temperatures, whilst, the "dark" ones represent the untreated surface temperatures. From figure (6.10) the follwing points can be concluded:-

1. The temperatures are highest at the surface.
2. The temperature differences are decrease with depth, such that by 10 cm there is little difference between the treated and untreated sand samples.
3. Sand temperatures at the surface and at both 5 cm and 10 cm depths increase

Table 6.13: Effect of Various Chemical Stabilizers on Baiji Dune Sand Surface Temperature.

Treats	Conc.*	Readings (°C)					
		1	2	3	4	5	Mean
PVA2	0.2%	31.7	29.7	25.8	34.4	27.7	29.9
	0.4%	31.9	29.8	25.9	34.5	27.9	30.0
F.E.	0.2 l m^{-2}	32.9	30.7	26.8	35.7	28.7	31.0
	0.4 l m^{-2}	33.3	30.8	27.0	35.9	28.8	31.2
B.E.	0.5 l m^{-2}	33.8	31.2	27.1	37.3	29.0	31.7
	1.0 l m^{-2}	34.0	31.2	27.2	37.6	29.2	31.8
Aq1	0.33%	33.1	30.6	27.0	35.4	28.6	30.9
	0.66%	33.2	30.7	27.1	35.8	28.8	31.0
Control		31.7	29.6	25.7	34.3	27.6	29.8
Air temperature		32∓1	30∓1	26∓1	35∓1	28∓1	30.2∓1

* All (%) are on the base of air-dry sand.

Table 6.14: Effect of Various Chemical Stabilizers on Baiji Dune Sand 5 cm Depth Temperature.

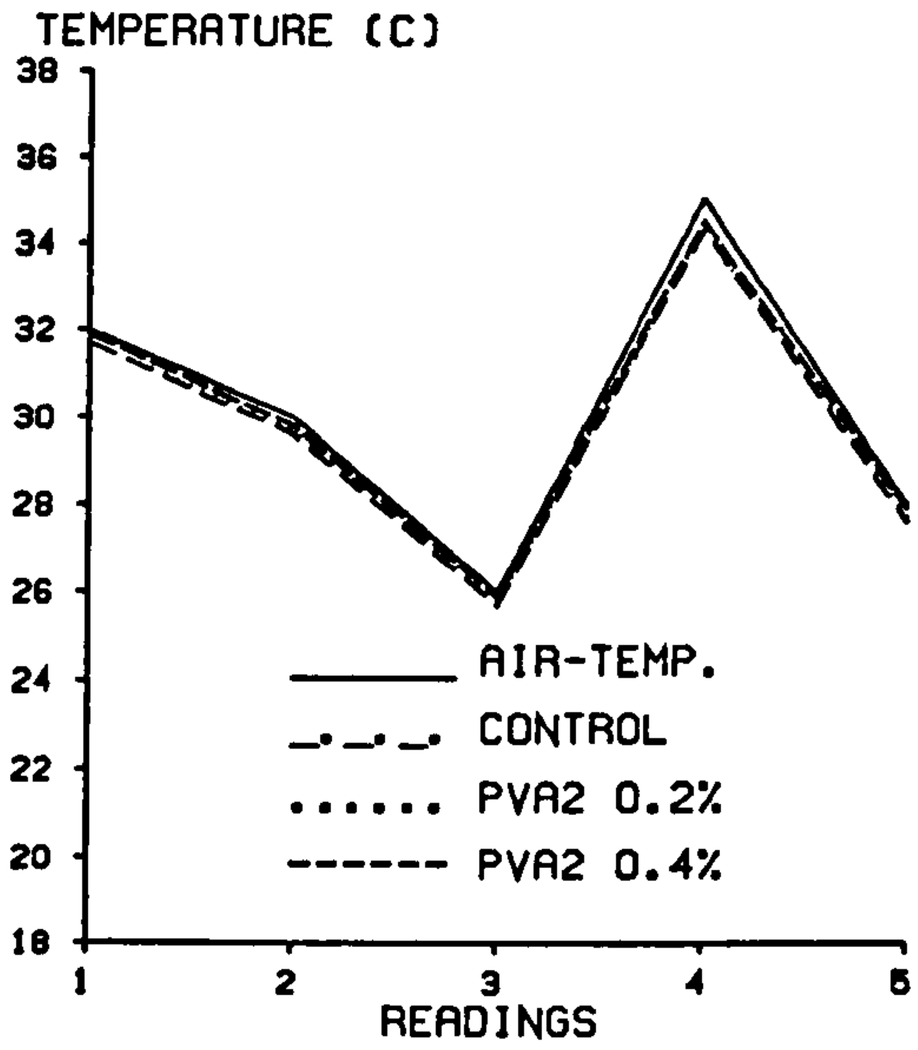
Treats	Conc.*	Readings (°C)					
		1	2	3	4	5	Mean
PVA2	0.2%	28.3	28.0	25.4	29.8	27.0	27.7
	0.4%	28.7	28.1	25.5	30.4	27.3	28.0
F.E.	0.2 l m^{-2}	29.1	29.0	25.6	30.5	27.7	28.4
	0.4 l m^{-2}	29.2	29.2	25.8	31.0	27.8	28.6
B.E.	0.5 l m^{-2}	30.7	29.8	25.7	31.0	27.8	29.0
	1.0 l m^{-2}	31.7	30.0	26.0	31.9	28.0	29.5
Aq1	0.33%	30.0	29.4	25.6	30.2	27.6	28.6
	0.66%	31.3	29.8	25.7	31.8	27.7	29.3
Control		28.2	27.6	25.3	29.7	27.3	27.6
Air temperature		32∓1	30∓1	26∓1	35∓1	28∓1	30.2∓1

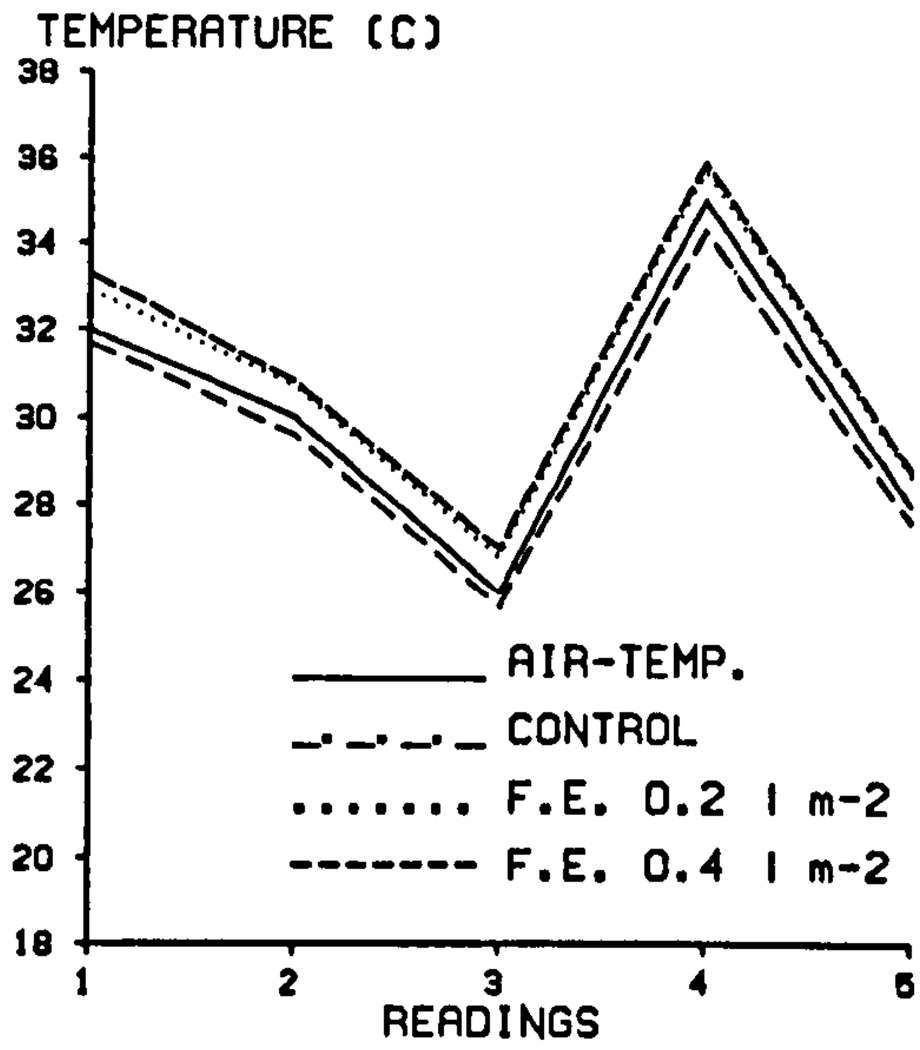
* All (%) are on the base of air-dry sand.

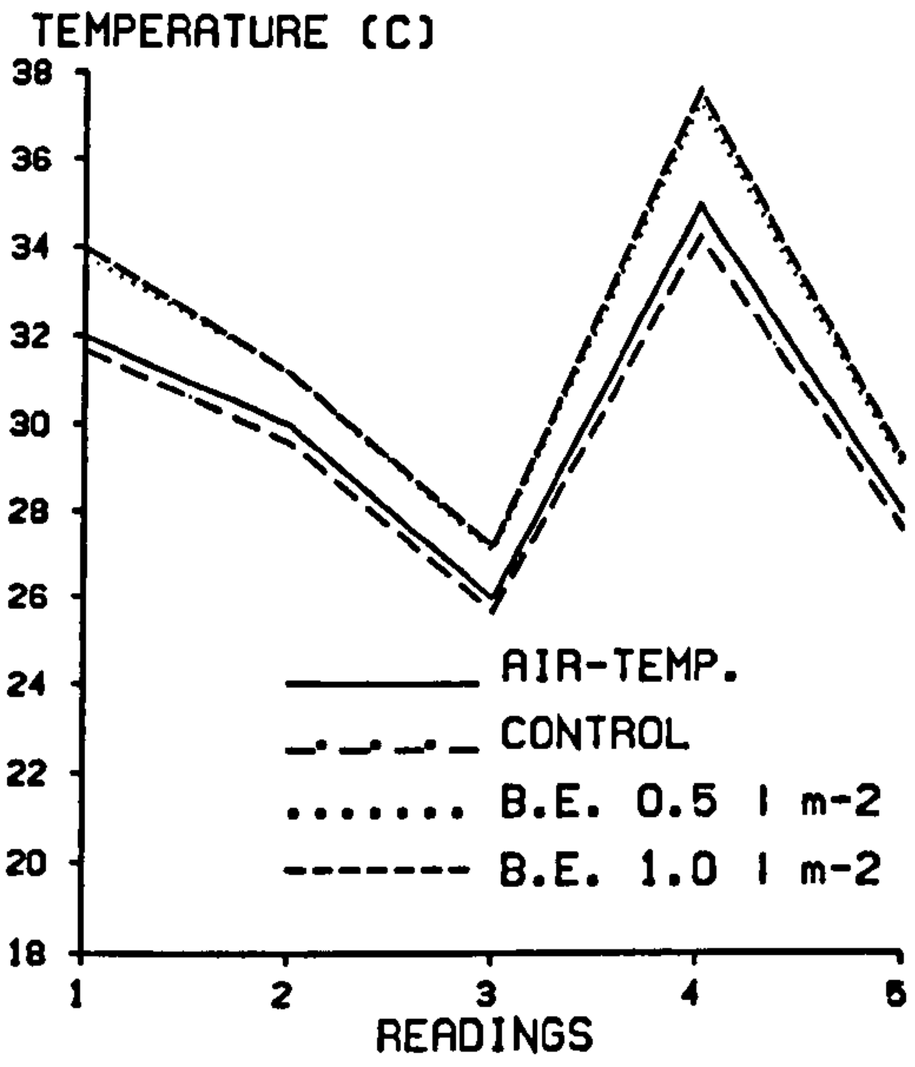
Table 6.15: Effect of Various Chemical Stabilizers on Baiji Dune Sand 10 cm Depth Temperature.

Treats	Conc.*	Readings (°C)					
		1	2	3	4	5	Mean
PVA2	0.2%	28.4	26.2	25.1	27.3	25.5	26.5
	0.4%	28.6	26.4	25.2	27.6	25.6	26.7
F.E.	0.2 l m^{-2}	28.4	26.3	25.2	27.4	25.5	26.6
	0.4 l m^{-2}	28.5	26.4	25.2	27.7	25.6	26.7
B.E.	0.5 l m^{-2}	28.5	26.5	25.3	27.9	25.8	26.8
	1.0 l m^{-2}	28.7	26.7	25.4	28.2	26.0	27.0
Aq1	0.33%	28.5	26.4	25.1	27.5	25.5	26.6
	0.66%	28.6	26.6	25.2	27.6	25.7	26.7
Control		28.4	26.1	25.0	27.1	25.3	26.4
Air temperature		32∓1	30∓1	26∓1	35∓1	28∓1	30.2∓1

* All (%) are on the base of air-dry sand.







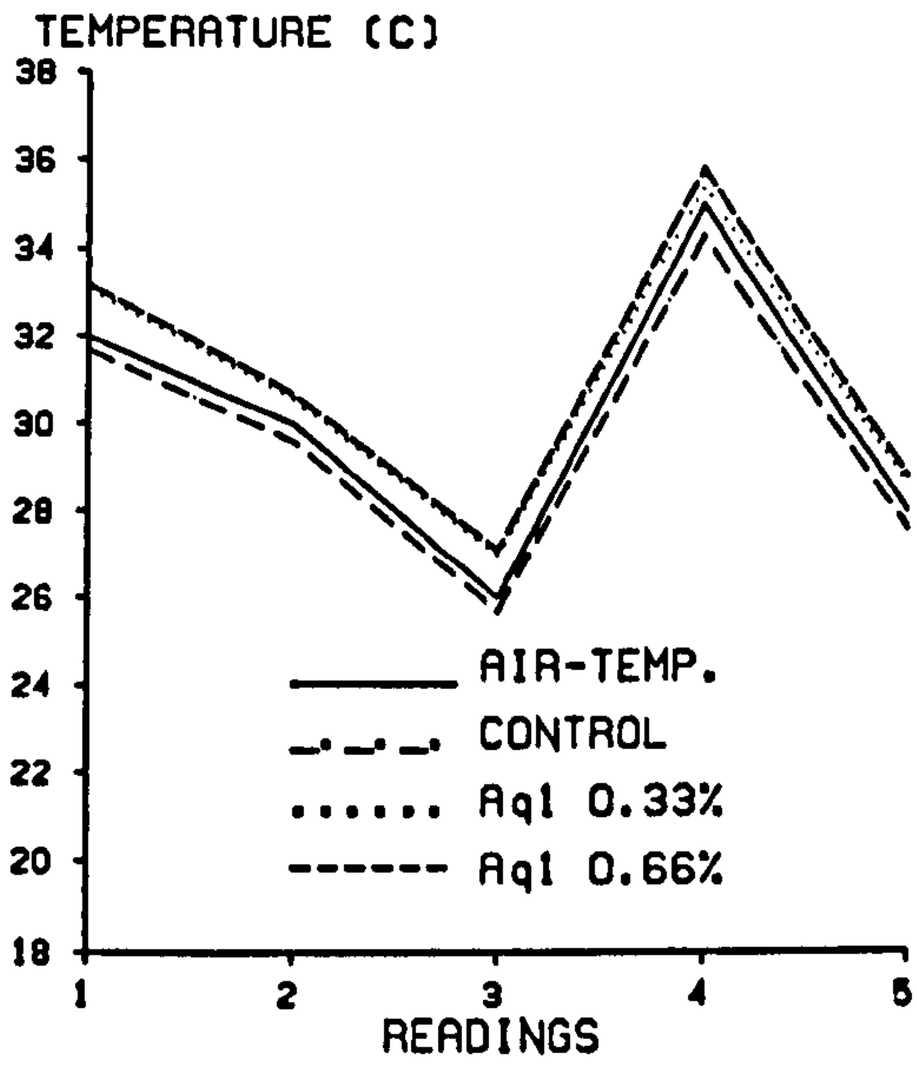


FIG. 6.7: EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE SURFACE TEMPERATURE OF BAIJI SAND.

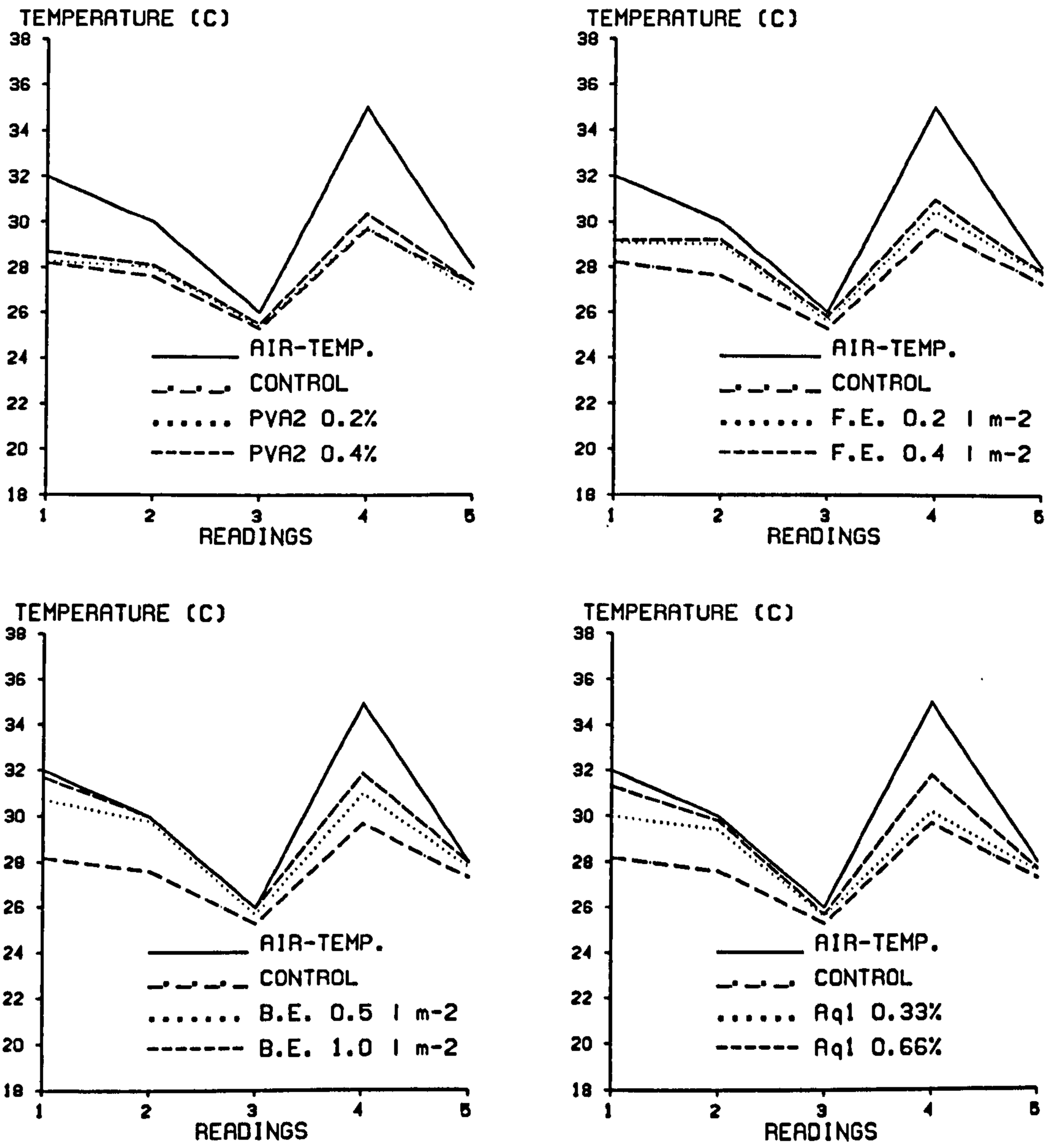


FIG. 6.8: EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE (5 cm DEPTH) TEMPERATURE OF BAIJI SAND.

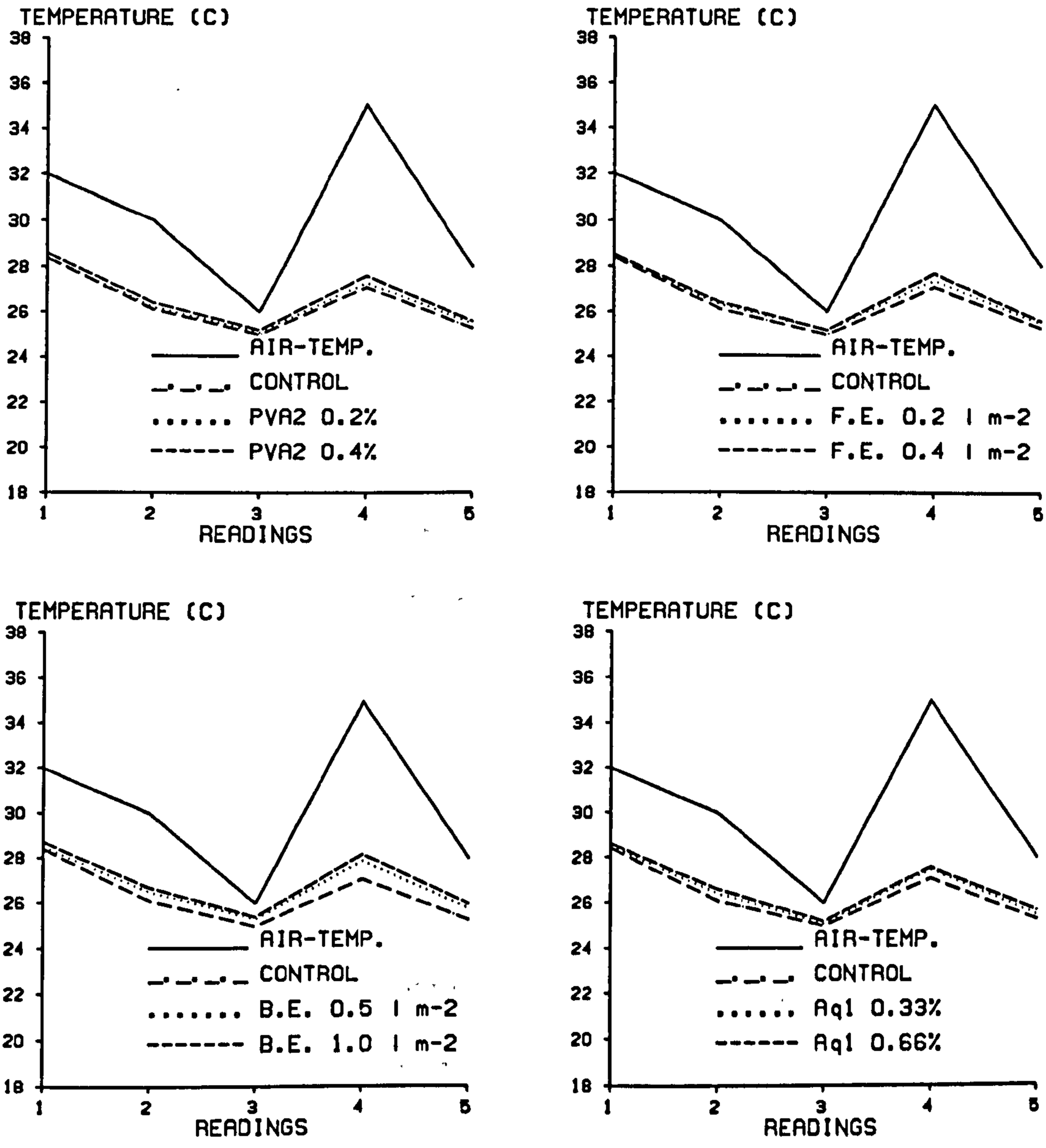
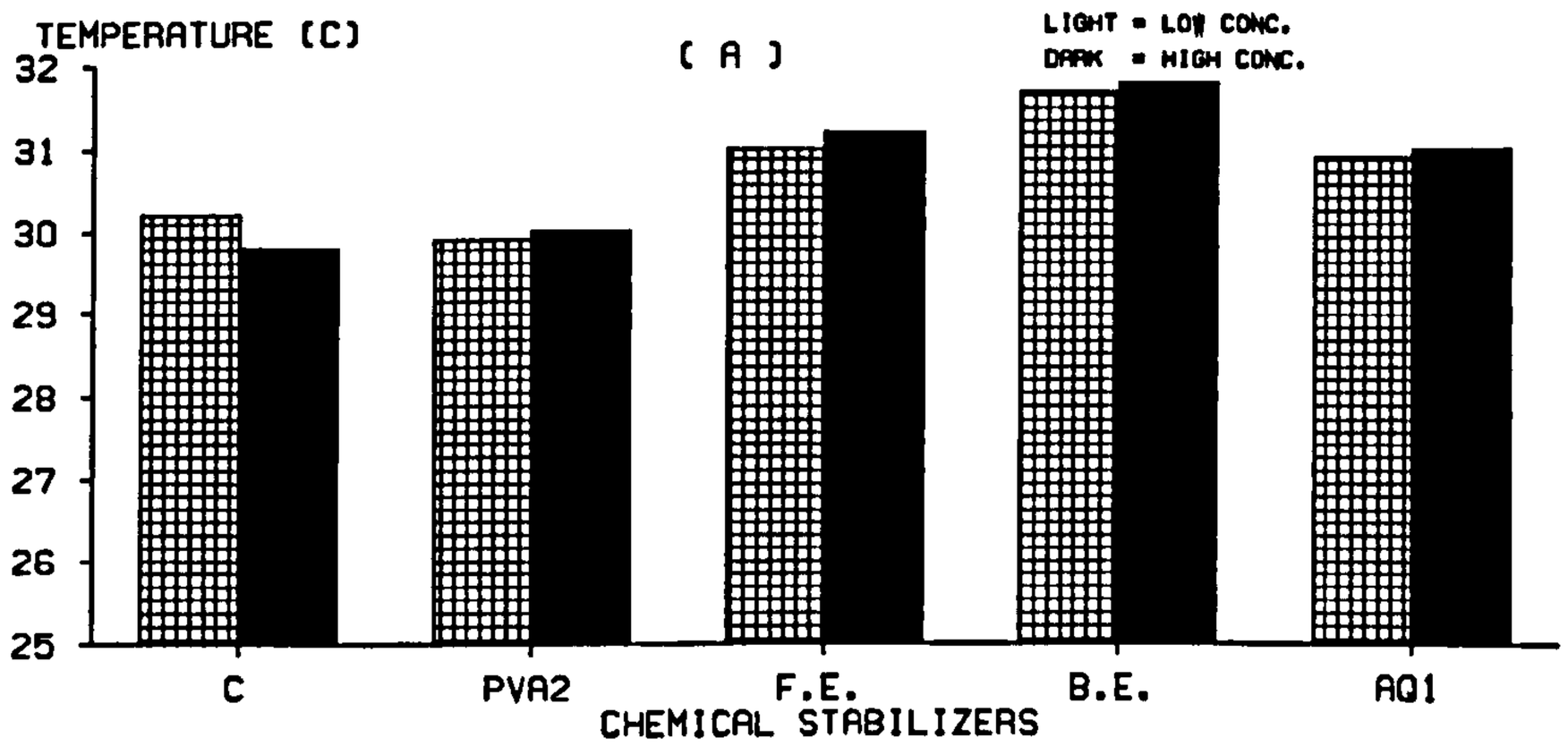
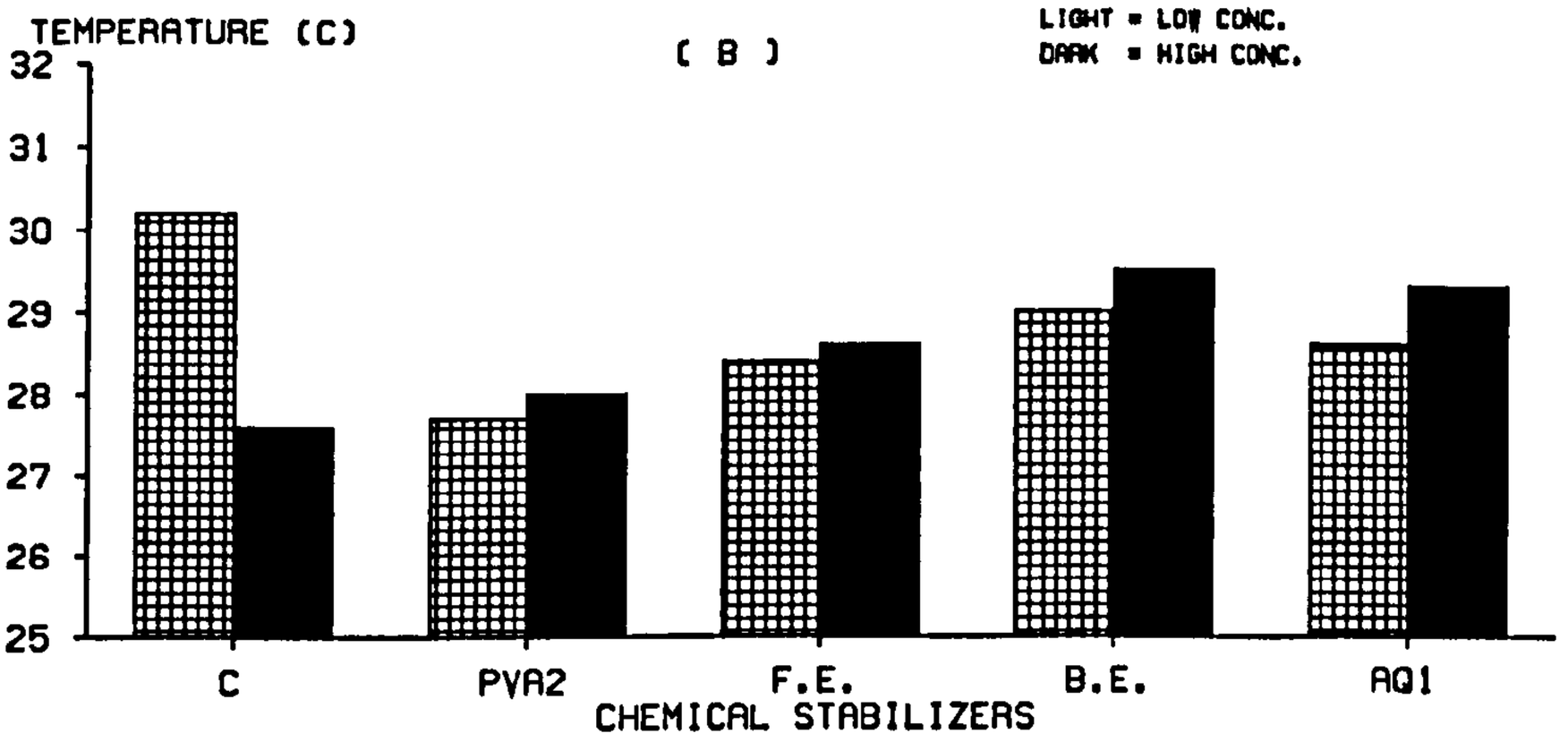


FIG. 6.9: EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE (10 cm DEPTH) TEMPERATURE OF BAIJI SAND.





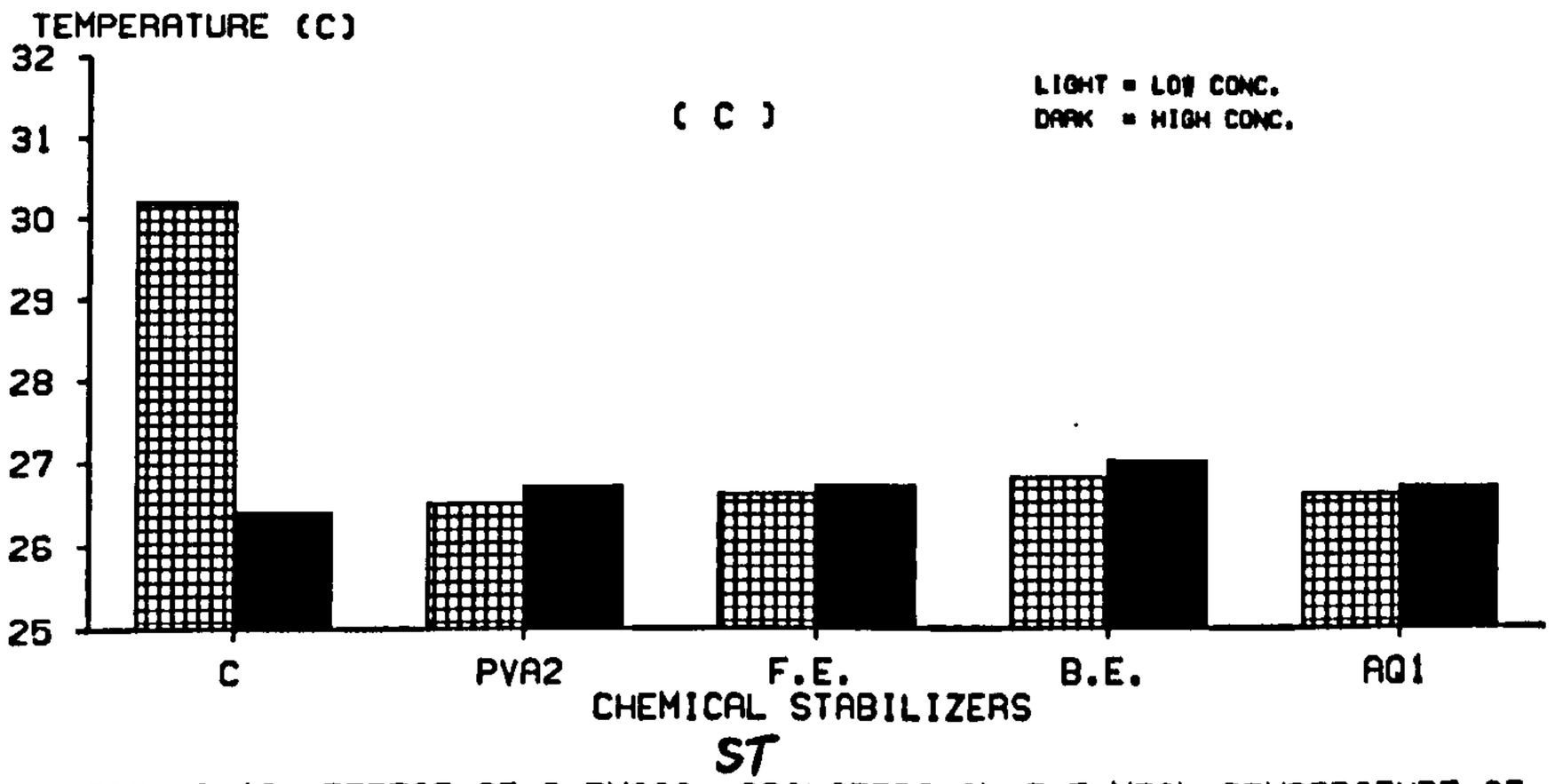


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FIG. 6.10: EFFECT OF CHEMICAL ABILIZERS ON THE MEAN TEMPERATURE OF BAIJI SAND AT: (A) SAND SURFACE; (B) 5 cm DEPTH; (C) 10 cm DEPTH

as the concentration of the chemicals applied increases.

4. The effect of various chemical materials on Baiji sand temperatures can be ranked as follows: B.E. > Aq1 ≥ F.E. > PVA2 ≥ Control

6.10 Effect of Soil Chemical Stabilizers on the Movement of Water Through the Sand

6.10.1 Techniques, Materials and Methods

The experiment described in section 5.1.2.2 was repeated using Baiji sand rather than Druridge Bay sand. The stabilizers used were: PVA2 (0.2% and 0.4%); F.E. (0.2 and 0.4 l m^{-2}); B.E. (0.5 and 1.0 l m^{-2}); Aq1 (0.33% and 0.66%) and Aq2 (200 and 250 gm m^{-2}). During the execution of the experiment it was found that these treatments reacted differently with the Baiji sand and, apart from PVA2, they rendered the samples impermeable or at best drastically reduced the infiltration rate. As a consequence the experiment was repeated using lower concentrations of the chemicals:-

- F.E. 0.14 and 0.18 l m^{-2},
- B.E. 0.3 and 0.4 l m^{-2},
- Aq1 0.33% and 0.50%,
- Aq2 150; 175; 200 and 225 gm m^{-2}

All chemicals were diluted with water to get the stated concentrations when applied at a rate of 6.0 l m^{-2}, and as previously the treatments were tested in triplicate. Measurements of input water data were later used for the calculation of the infiltration rates and accumulated infiltrations; whilst, the output water data (10 minutes after the first percolated water drop) were used to calculate the saturated hydraulic conductivities and the intrinsic permeabilities (Klute, 1965).

6.10.2 Results and Discussions

a. Effect of the Chemical Stabilizers on Infiltration Rate and Accumulated Infiltration:

Figures (6.11 - 6.15) and (6.16 - 6.20) illustrate the effect of the chemical stabilizers on both the infiltration rates and accumulated infiltrations of Baiji sands.

The results indicate, as in the case of Druridge Bay sand, the application of PVA2 as surface mulches increased both infiltration rate and accumulated infiltration of Baiji sand when compared with the control. Both increased as the chemical concentration increased. When compared with the control, the remaining chemicals, F.E. (140 and 180 ml m^{-2}); B.E. (0.3 and 0.4 l m^{-2}); Aq1 (0.33% and 0.50%) and Aq2 (150; 175; 200 and 225 gm m^{-2}) reduced both infiltration characteristics of the sand in proportion to their concentrations. The possible cause of the changes in infiltration rates and accumulated infiltrations were discussed in detail in chapter 5 section 5.1.2.3.

The initial high infiltration rates fall rapidly to their steady states as the time elapsed, within 8 - 12 minutes of the elapsed time all samples had reached their steady states.

Whilst the results from Baiji sand experiments are exact agreement with those of the Druridge Bay sand experiments. The actual infiltration rates and accumulated infiltrations of all Druridge Bay samples were much higher than those of Baiji sand samples. This was almost certainly due to the coarser sand particles of Druridge Bay sand in comparison with those of Baiji sand. With the reduced chemical concentrations used, all the results of Baiji sands were in excess of the minimum acceptable infiltration rate of 0.25 cm hr^{-1} (Richards, 1969).

Again, as in the case of Druridge Bay sand samples, good linear relationships are indicated in all figures (6.16 - 6.20), especially after the first 6 minutes

Fig. 6.11 : Effect of PVA2 on Infiltration Rate in Baiji Sand (Lab. Test).

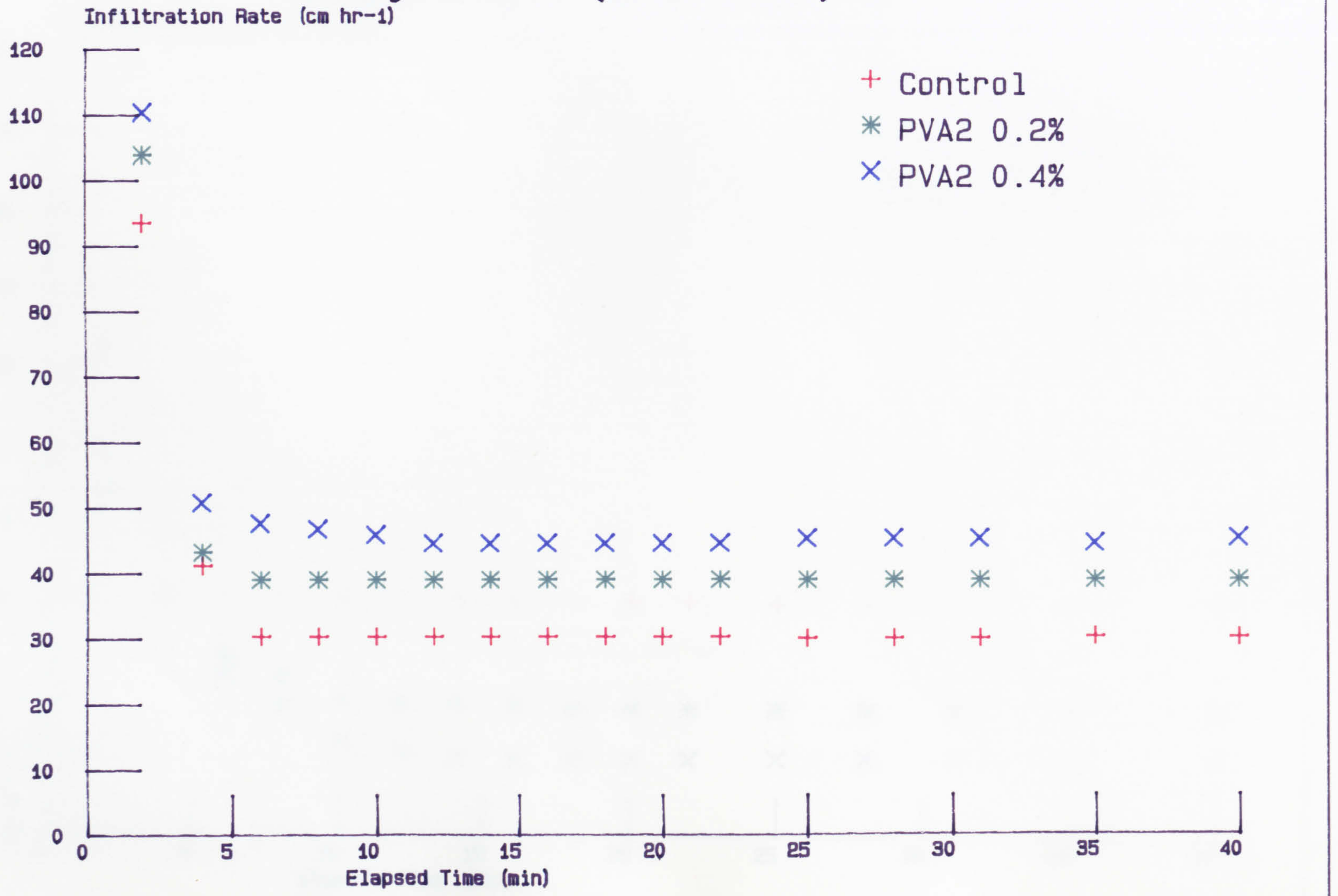


Fig. 6.12 : Effect of F.E. on Infiltration Rate in Baiji Sand (Lab. Test).

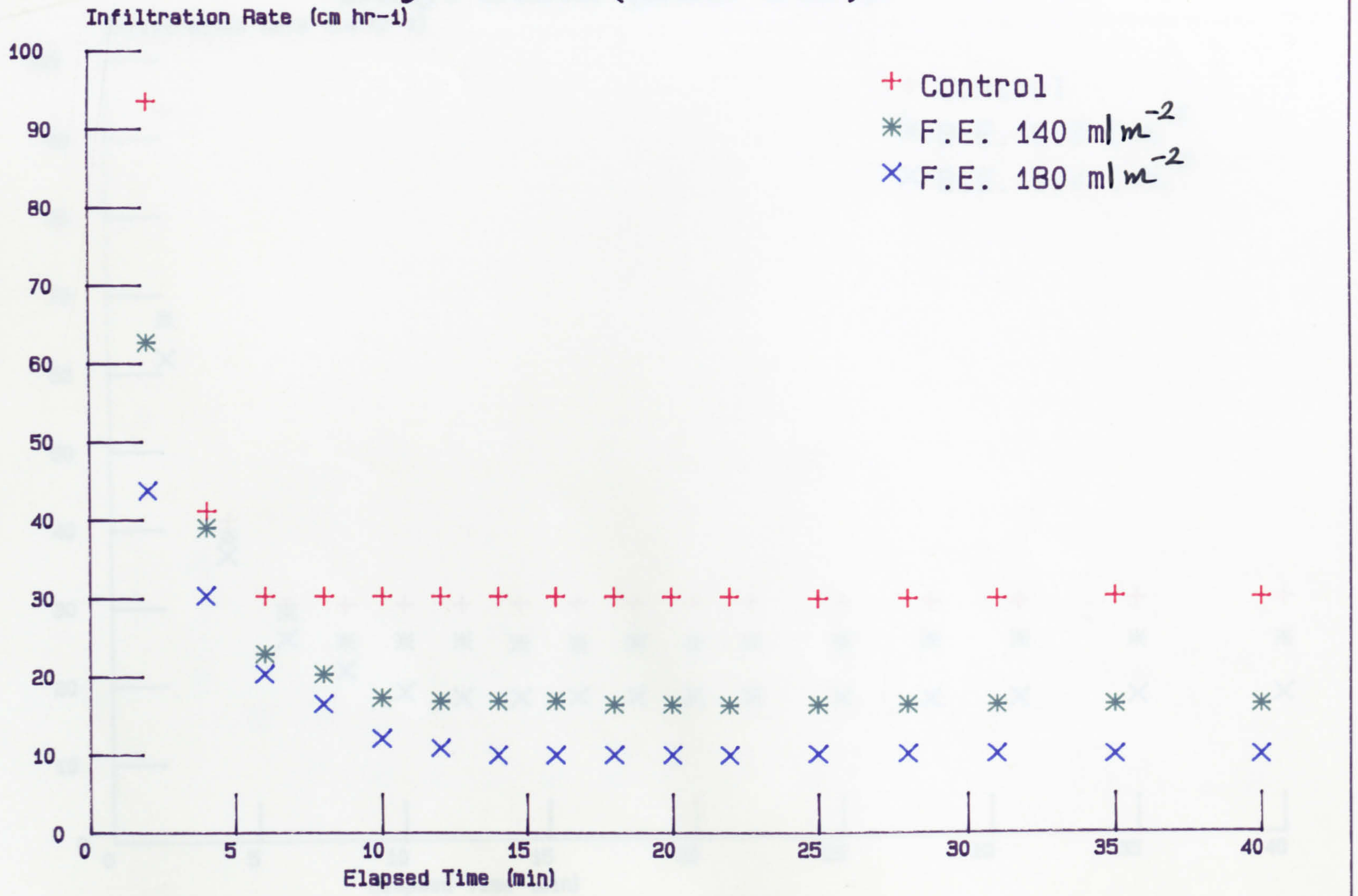


Fig. 6.13 : Effect of B.E. on Infiltration Rate in Baiji Sand (Lab. Test).

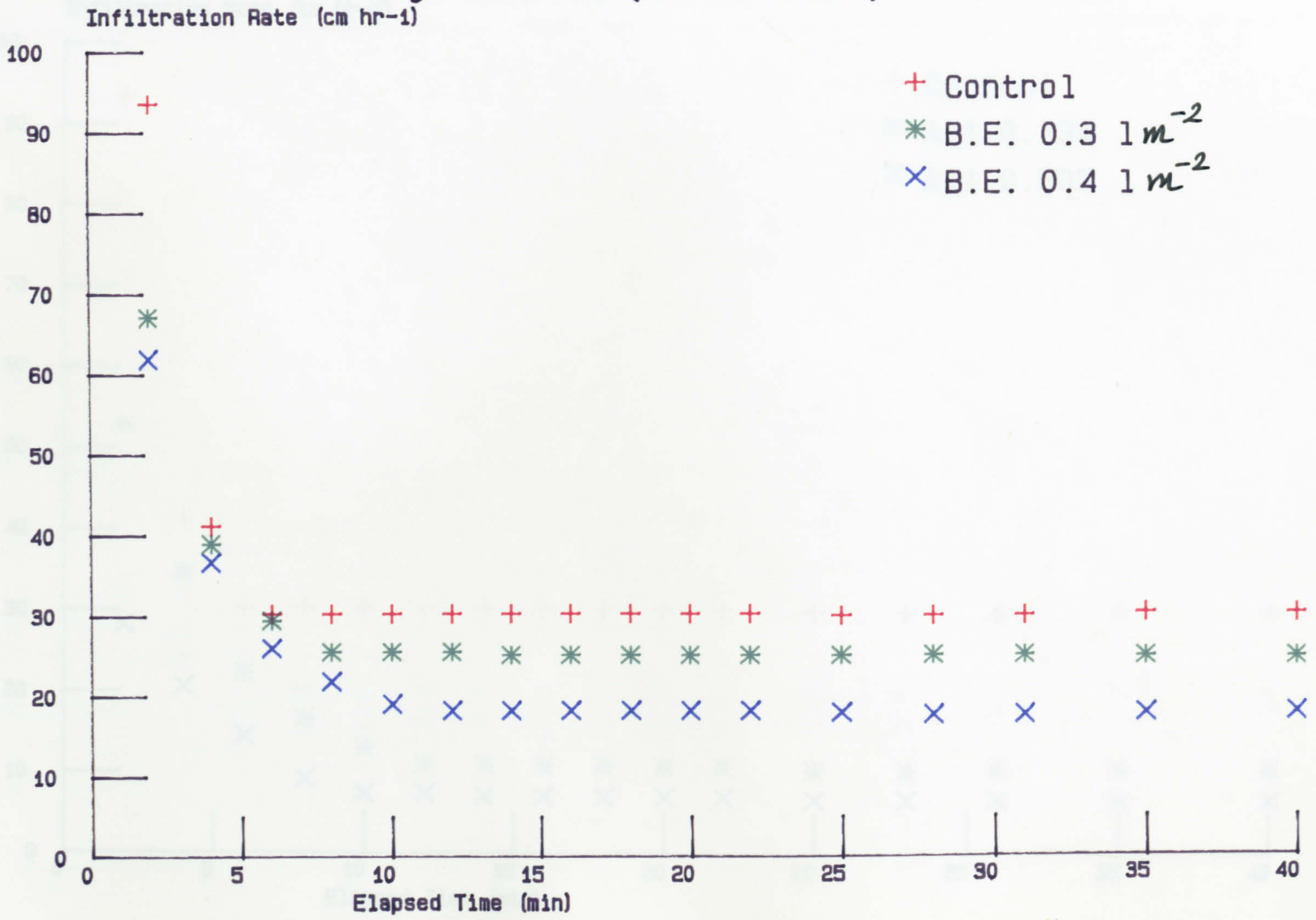


Fig. 6.14 : Effect of Aq1 on Infiltration Rate in Baiji Sand (Lab. Test).

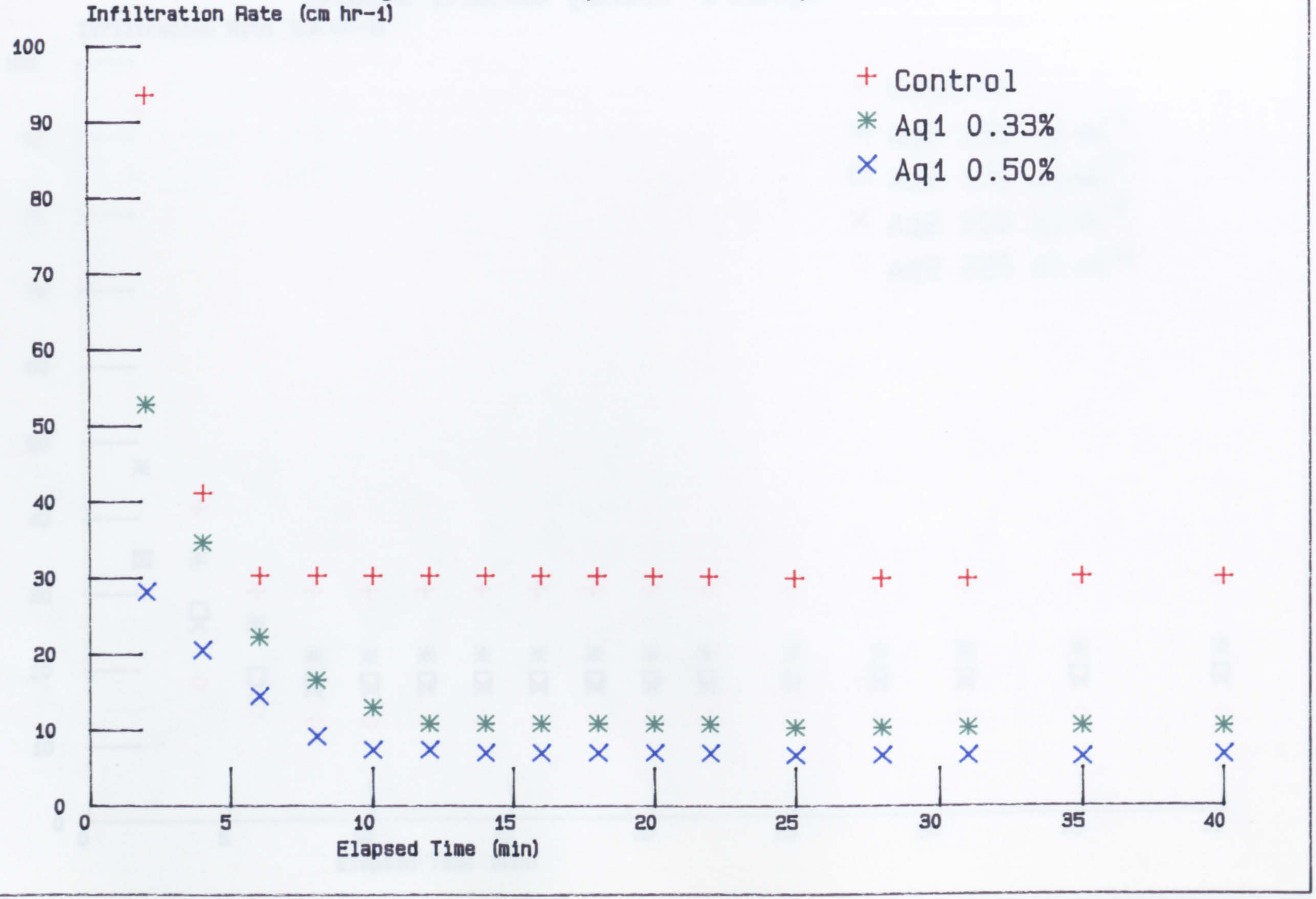


Fig. 6.15: Effect of Aq2 on Infiltration Rate in Baiji Sand (Lab. Test).

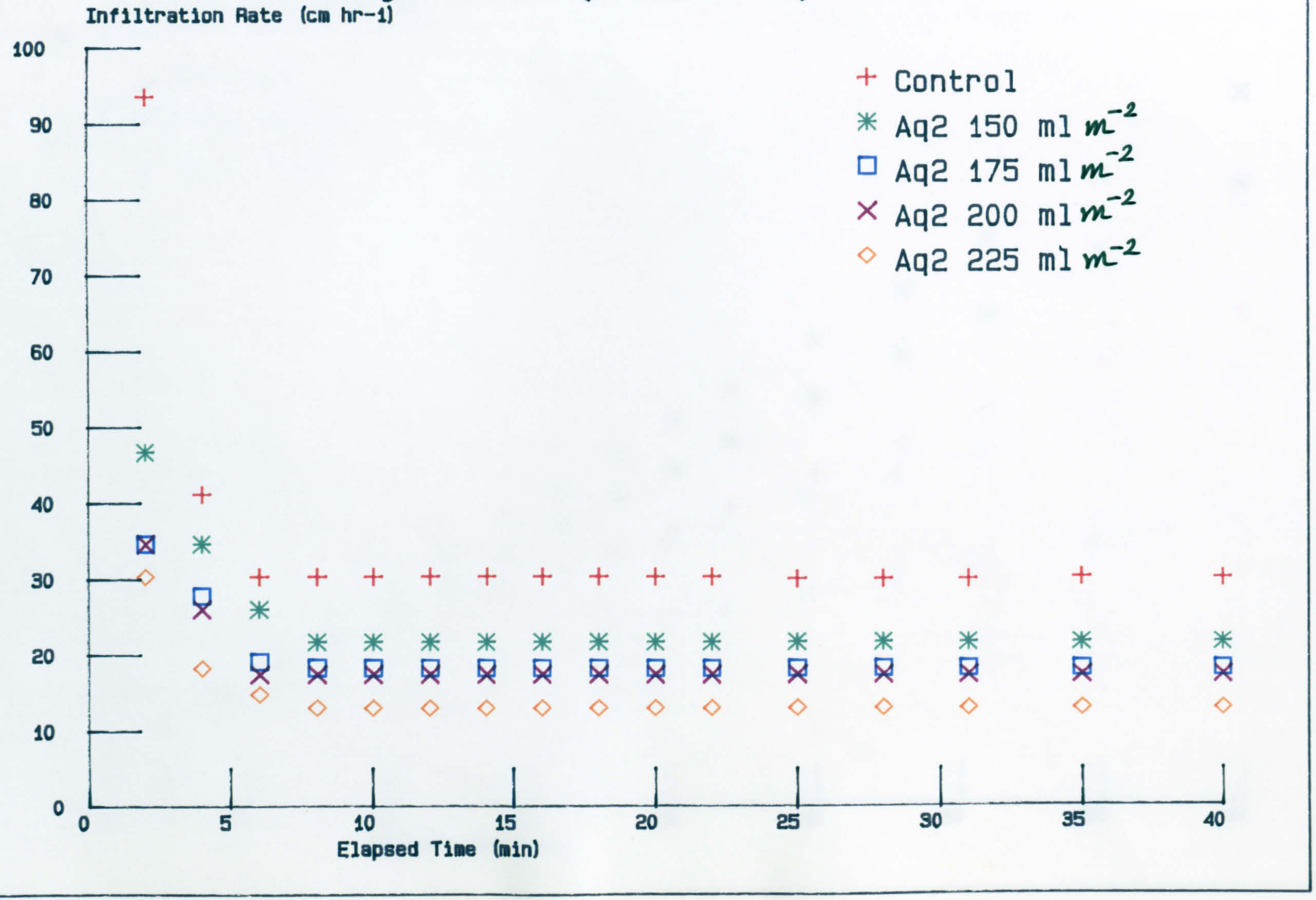


Fig. 6.16 : Effect of PVA2 on Accumulated Infiltr— in Baiji Sand (Lab Test).

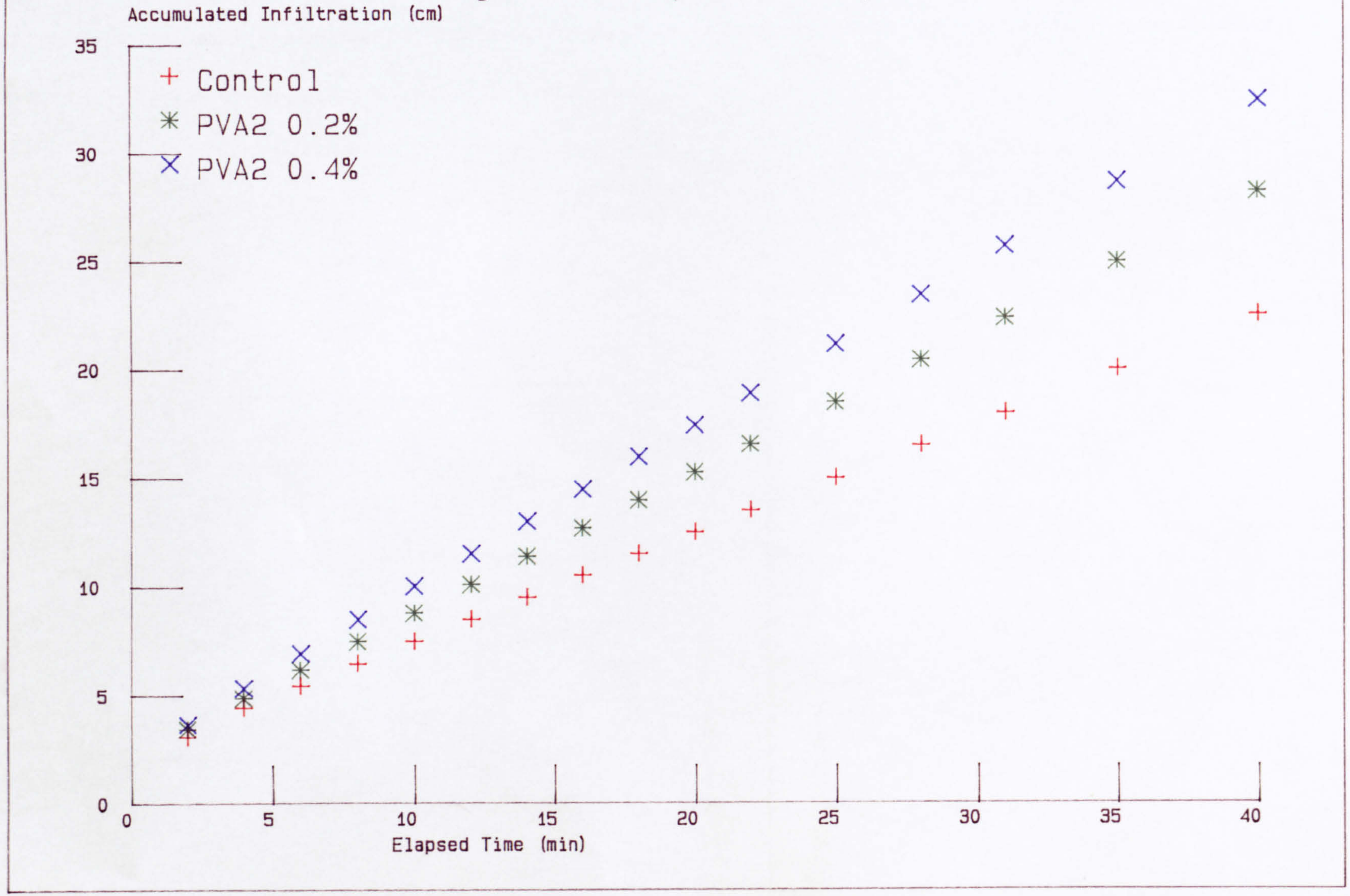


Fig. 6.17: Effect of F.E. on Accumulated Infiltration in Baiji Sand (Lab. Test).

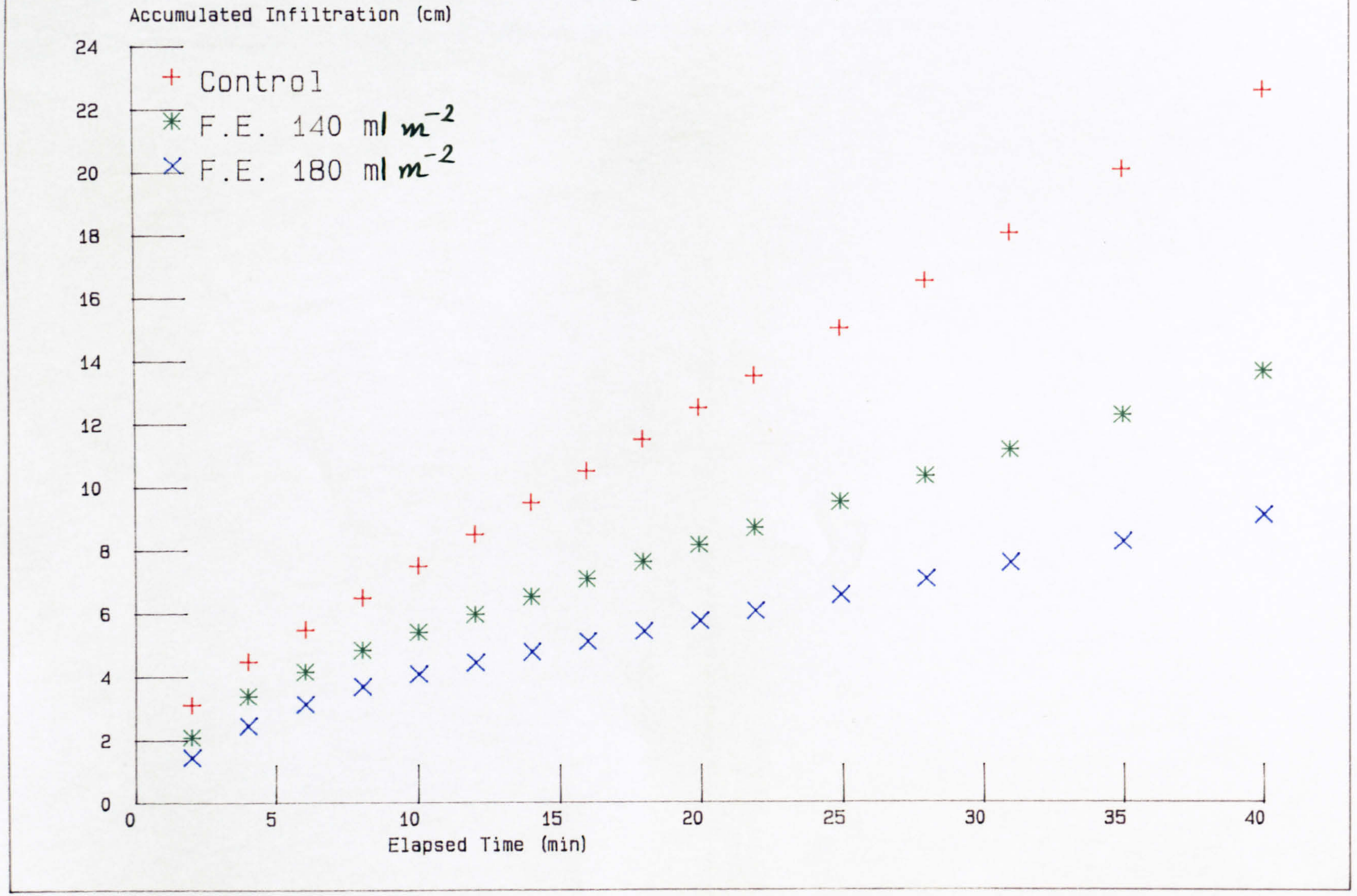


Fig. 6.18 : Effect of B.E. on Accumulated Infiltration in Baiji Sand (Lab. Test).

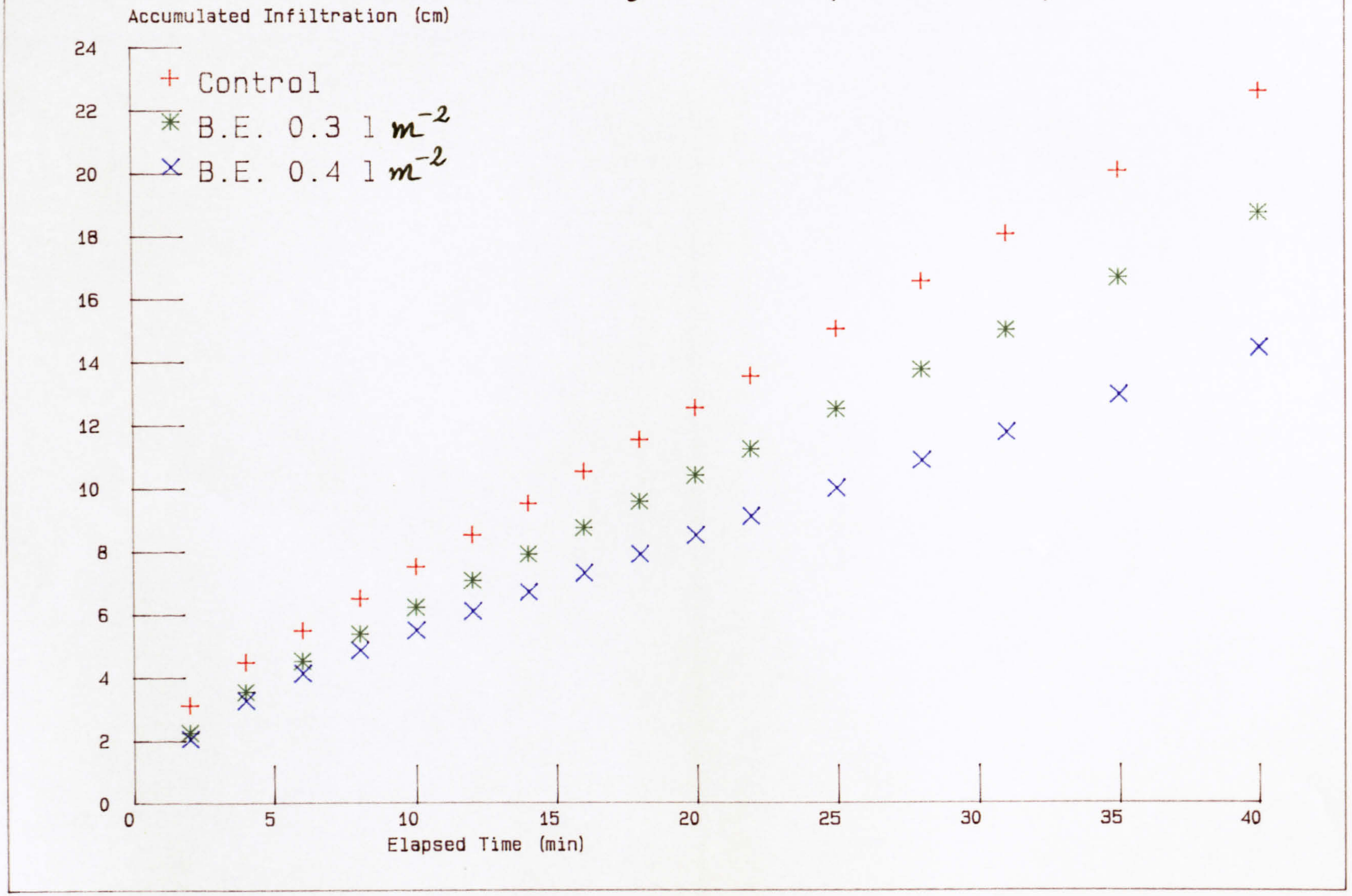


Fig. 6.19 : Effect of Aq1 on Accumulated Infiltration in Baiji Sand (Lab. Test).

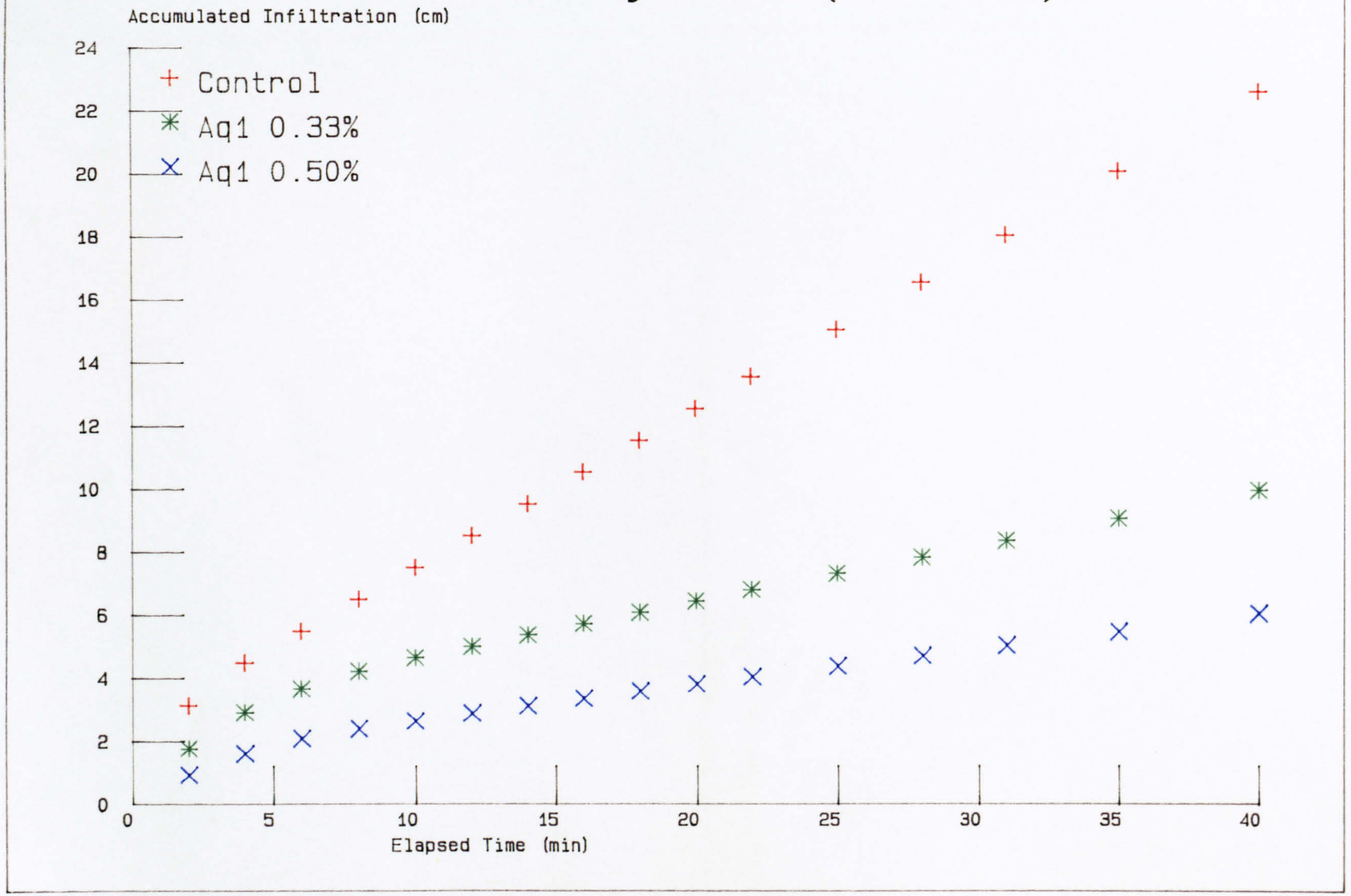
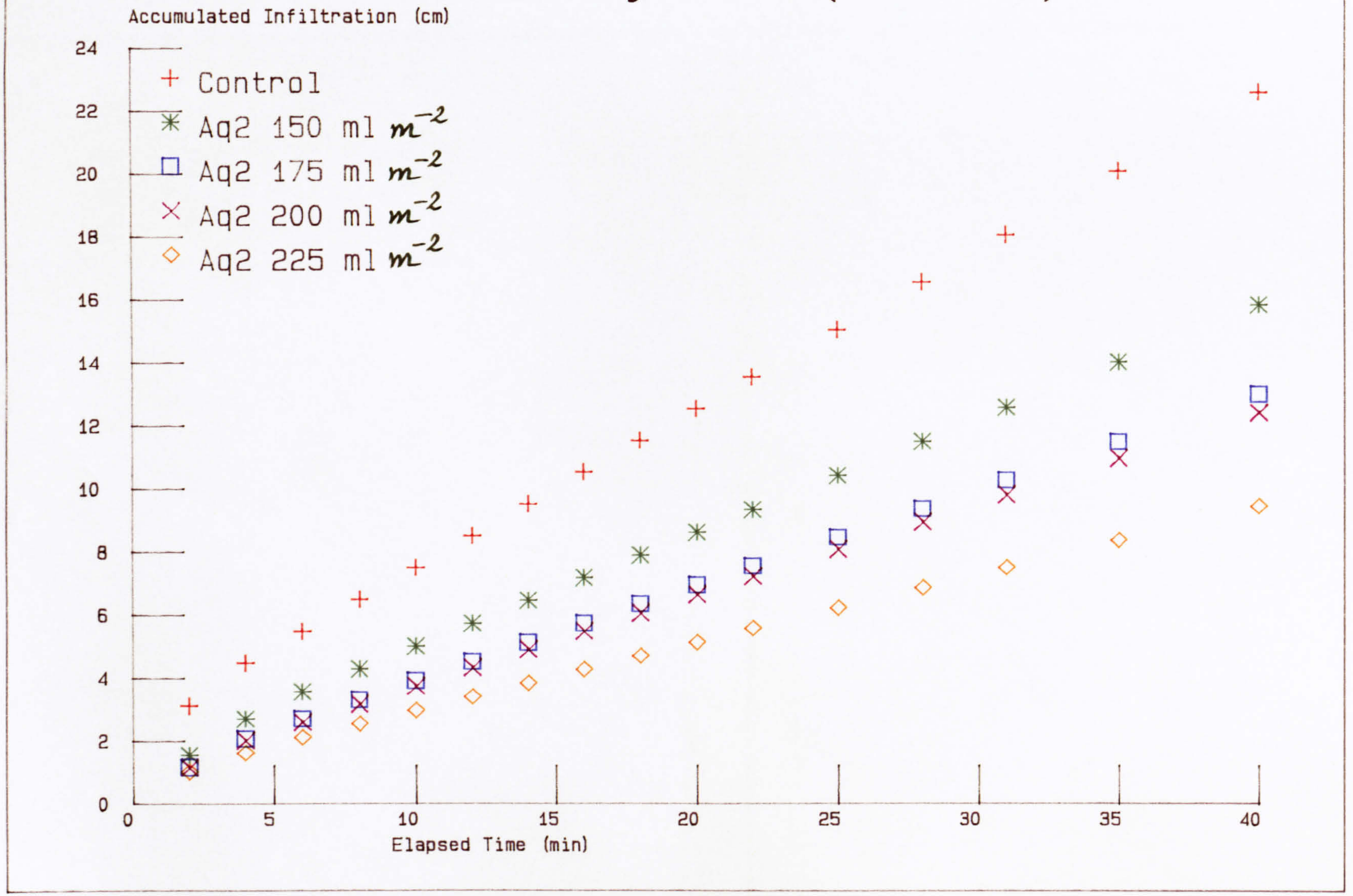


Fig. 6.20: Effect of Aq2 on Accumulated Infiltration in Baiji Sand (Lab. Test).



of the tests. The regression coefficients (r) between the observed accumulated infiltrations data and the elapsed time derived from the untreated and treated sand samples are extremely high (table 6.16).

Table 6.16: Regression Coefficients and a and b Constant Values for the Relationship Between Accumulated Infiltration (cm) and the Elapsed Time (min).

Treats	Conc.*	a	b	r
Control	—	2.409	0.507	1.000
PVA2	0.2%	2.280	0.651	1.000
	0.4%	2.413	0.753	1.000
F.E.	140 ml m^{-2}	2.322	0.289	0.997
	180 ml m^{-2}	1.968	0.185	0.990
B.E.	0.3 l m^{-2}	1.866	0.425	1.000
	0.4 l m^{-2}	2.183	0.313	0.998
Aq1	0.33%	2.369	0.197	0.989
	0.50%	1.265	0.124	0.991
Aq2	150 gm m^{-2}	1.260	0.367	1.000
	175 gm m^{-2}	0.814	0.306	1.000
	200 gm m^{-2}	0.802	0.291	1.000
	225 gm m^{-2}	0.749	0.218	1.000

* All the percentages are on the base of air-dry sand; Both (a) and (b) are the accumulated infiltration (Y) parameters of regression equation, (a) is the intercept on Y axis, while (b) is the slope of the linear regression line; rtab at (0.01) d.f.(14) = 0.6226.

b. Effect of Soil Stabilizers on Sand Saturated Hydraulic Conductivity and Intrinsic Permeability:

Tables (6.17 - 6.26) list the saturated hydraulic conductivities (cm hr^{-1}) and sand intrinsic permeabilities (cm^2) of the Baiji sand samples.

The results indicate that, as in the cases of both infiltration rate and accumulated infiltration, both saturated hydraulic conductivity and intrinsic permeability of Baiji sand increased with the applications of the PVA2 (0.2% and 0.4%), whilst, they were reduced by applications of the other chemical treatments. Furthermore, the reduction in both properties was greatest with the higher concentrations of the stabilizers.

The effect of the stabilizers in increasing hydraulic conductivity and intrinsic permeability can be ranked as follows: PVA2 0.4% > PVA2 0.2% > Control > B.E. 0.3 l m^{-2}> Aq2 150 gm m^{-2}> Aq2 175 gm m-2 > B.E. 0.4 l m^{-2}> Aq2 200 gm m^{-2}> F.E. 140 ml m^{-2}> Aq2 225 gm m^{-2}> Aq1 0.33% > F.E. 180 ml m^{-2}> Aq1 0.50%.

The possible causes of the changes in saturated hydraulic conductivities and intrinsic permeabilities in sand samples when treated with various chemicals has already been discussed in detail in chapter 5 section 5.1.2.3b.

Comparing the results in table (6.27) with those produced by O'Neal (1952) (table 5.25 in chapter 5), all saturated hydraulic conductivity and intrinsic permeability values of both untreated and treated samples from Baiji fall within the moderate to the very rapid classes. The different reactions of Baiji sand and Druridge Bay sand to the initial concentrations of stabilizers used, emphasises the need to examine the properties of the materials to be stabilized and thus adjust the concentrations of chemicals used. i.e. concentrations found satisfactory for one site must not be extrapolated to another.

Table 6.17: Effect of PVA2 on Saturated Hydraulic Conductivity of Baiji Sand.

Time	Saturated Hydraulic Conductivity (cm hr^{-1}) PVA2 Concentrations*		
(min)	0.0%	0.2%	0.4%
2.00	25.641	32.996	37.722
4.00	25.641	32.996	37.722
6.00	25.641	32.996	37.722
8.00	25.641	32.996	37.722
10.00	25.641	32.996	37.722
12.00	25.641	32.996	37.722
15.00	25.382	32.947	38.330
18.00	25.382	32.947	38.330
21.00	25.382	32.947	38.330
25.00	25.637	32.949	37.722
30.00	25.486	32.949	38.382

* All (%) are on the base of air-dry sand.

Table 6.18: Effect of F.E. on Saturated Hydraulic Conductivity of Baiji Sand.

Time	Saturated Hydraulic Conductivity (cm hr^{-1}) F.E. Concentrations		
(min)	0.0 l m^{-2}	140 ml m^{-2}	180 ml m^{-2}
2.00	25.641	14.315	9.187
4.00	25.641	14.315	8.425
6.00	25.641	14.315	8.425
8.00	25.641	13.912	8.425
10.00	25.641	13.912	8.425
12.00	25.641	13.912	8.425
15.00	25.382	13.910	8.527
18.00	25.382	13.910	8.527
21.00	25.382	13.910	8.527
25.00	25.637	13.912	8.429
30.00	25.486	13.911	8.378

Table 6.19: Effect of B.E. on Saturated Hydraulic Conductivity of Baiji Sand.

Time (min)	Saturated Hydraulic Conductivity (cm hr^{-1}) B.E. Concentrations		
	0.0 l m^{-2}	0.3 l m^{-2}	0.4 l m^{-2}
2.00	25.641	21.626	15.385
4.00	25.641	21.275	15.385
6.00	25.641	21.275	15.385
8.00	25.641	21.275	15.385
10.00	25.641	21.275	15.385
12.00	25.641	21.275	15.385
15.00	25.382	21.221	15.131
18.00	25.382	21.221	14.877
21.00	25.382	21.221	14.877
25.00	25.637	21.070	15.029
30.00	25.486	20.967	15.080

Table 6.20: Effect of Aq1 on Saturated Hydraulic Conductivity of Baiji Sand.

Time (min)	Saturated Hydraulic Conductivity (cm hr^{-1}) Aq1 Concentrations*		
	0.0%	0.33%	0.50%
2.00	25.641	9.187	6.242
4.00	25.641	9.187	5.890
6.00	25.641	9.187	5.890
8.00	25.641	9.187	5.890
10.00	25.641	9.187	5.890
12.00	25.641	9.187	5.890
15.00	25.382	8.781	5.636
18.00	25.382	8.781	5.636
21.00	25.382	8.781	5.636
25.00	25.637	8.985	5.484
30.00	25.486	8.935	5.738

* All (%) are on the base of air-dry sand.

Table 6.21: Effect of Aq2 on Saturated Hydraulic Conductivity of Baiji Sand.

Time	Saturated Hydraulic Conductivity (cm hr^{-1})				
			Aq2	Concentrations	
(min)	0.0 gm m^{-2}	150 gm m^{-2}	175 gm m^{-2}	200 gm m^{-2}	225 gm m^{-2}
2.00	25.641	18.330	15.385	14.674	10.967
4.00	25.641	18.330	15.385	14.674	10.967
6.00	25.641	18.330	15.385	14.674	10.967
8.00	25.641	18.330	15.385	14.674	10.967
10.00	25.641	18.330	15.385	14.674	10.967
12.00	25.641	18.330	15.385	14.674	10.967
15.00	25.382	18.330	15.385	14.672	10.965
18.00	25.382	18.330	15.385	14.672	10.965
21.00	25.382	18.330	15.385	14.672	10.965
25.00	25.637	18.326	15.385	14.674	10.967
30.00	25.486	18.327	15.382	14.673	10.966

Table 6.22: Effect of PVA2 on the Intrinsic Permeability of Baiji Sand.

Time	Intrinsic Permeability (cm^2) x 10^{-7}		
	PVA2 Concentrations*		
(min)	0.0%	0.2%	0.4%
2.0	0.738	0.949	1.085
4.0	0.738	0.949	1.085
6.0	0.738	0.949	1.085
8.0	0.738	0.949	1.085
10.0	0.738	0.949	1.085
12.0	0.738	0.949	1.085
15.0	0.730	0.948	1.103
18.0	0.730	0.948	1.103
21.0	0.730	0.948	1.103
25.0	0.738	0.948	1.085
30.0	0.733	0.948	1.104

* All (%) are on the base of air-dry sand.

Table 6.23: Effect of F.E. on the Intrinsic Permeability of Baiji Sand.

Time (min)	Intrinsic Permeability (cm^2) x 10^{-7} F.E. Concentrations		
	0.0 ml m^{-2}	140 ml m^{-2}	180 ml m^{-2}
2.0	0.738	0.412	0.264
4.0	0.738	0.412	0.242
6.0	0.738	0.412	0.242
8.0	0.738	0.400	0.242
10.0	0.738	0.400	0.242
12.0	0.738	0.400	0.242
15.0	0.730	0.400	0.245
18.0	0.730	0.400	0.245
21.0	0.730	0.400	0.245
25.0	0.738	0.400	0.242
30.0	0.733	0.400	0.241

Table 6.24: Effect of B.E. on the Intrinsic Permeability of Baiji Sand.

Time (min)	Intrinsic Permeability (cm^2) x 10^{-7} B.E. Concentrations		
	0.0 l m^{-2}	0.3 l m^{-2}	0.4 l m^{-2}
2.0	0.738	0.622	0.443
4.0	0.738	0.612	0.443
6.0	0.738	0.612	0.443
8.0	0.738	0.612	0.443
10.0	0.738	0.612	0.443
12.0	0.738	0.612	0.443
15.0	0.730	0.611	0.435
18.0	0.730	0.611	0.428
21.0	0.730	0.611	0.428
25.0	0.738	0.606	0.432
30.0	0.733	0.603	0.434

Table 6.25: Effect of Aq1 on the Intrinsic Permeability of Baiji Sand.

Time	Intrinsic Permeability (cm^2) x 10^{-7} Aq1 Concentrations*		
(min)	0.0%	0.33%	0.50%
2.0	0.738	0.264	0.180
4.0	0.738	0.264	0.169
6.0	0.738	0.264	0.169
8.0	0.738	0.264	0.169
10.0	0.738	0.264	0.169
12.0	0.738	0.264	0.169
15.0	0.730	0.253	0.162
18.0	0.730	0.253	0.162
21.0	0.730	0.253	0.162
25.0	0.738	0.258	0.158
30.0	0.733	0.257	0.165

* All (%) are on the base of air-dry sand.

Table 6.26: Effect of Aq2 on the Intrinsic Permeability of Baiji Sand.

Time	Intrinsic Permeability (cm^2) x 10^{-7} Aq2 Concentrations				
(min)	0.0 gm m^{-2}	150 gm m^{-2}	175 gm m^{-2}	200 gm m^{-2}	225 gm m^{-2}
2.0	0.738	0.527	0.443	0.422	0.316
4.0	0.738	0.527	0.443	0.422	0.316
6.0	0.738	0.527	0.443	0.422	0.316
8.0	0.738	0.527	0.443	0.422	0.316
10.0	0.738	0.527	0.443	0.422	0.316
12.0	0.738	0.527	0.443	0.422	0.316
15.0	0.730	0.527	0.443	0.422	0.315
18.0	0.730	0.527	0.443	0.422	0.315
21.0	0.730	0.527	0.443	0.422	0.315
25.0	0.738	0.527	0.443	0.422	0.316
30.0	0.733	0.527	0.443	0.422	0.315

Table 6.27: Hydraulic Conductivity and Intrinsic Permeability (Mean of Three Replicates) of Baiji Sands Treated With Various Chemical Stabilizers.

Treats	Conc.*	Hydraulic Conductivity ($cm\ hr^{-1}$)	Intrinsic Permeability (cm^2) x 10^{-7}
Control	—	25.56	0.735
PVA2	0.2%	32.97	0.949
	0.4%	37.95	1.092
F.E.	140 ml m^{-2}	13.96	0.403
	180 ml m^{-2}	8.52	0.257
B.E.	0.3 l m^{-2}	21.25	0.611
	0.4 l m^{-2}	15.21	0.438
Aq1	0.33%	9.04	0.260
	0.50%	5.80	0.167
Aq2	150 gm m^{-2}	18.33	0.527
	175 gm m^{-2}	15.39	0.443
	200 gm m^{-2}	14.67	0.422
	225 gm m^{-2}	10.97	0.316

* All (%) are on the base of air-dry sand.

CHAPTER 7

EFFECT OF SOIL CHEMICAL STABILIZERS ON EROSION

7.1 Introduction

The instability of the surface layer of the sand dunes is one of the most important reasons for sand losses through wind and water erosion. In Druridge Bay, the sand dunes erode due to the combination of high rainfall erosivity, complex sloping topography, strong winds especially in winter and the highly erodible loose sand. Exclusive erosion of the dunes could cause problems to the nearby farms, roads and the villages, thus by various means, both Northumberland County Council and the National Trust endeavour to prevent erosion.

Soil erosion is affected by many factors such as the erosivity of the rainfall (water erosion), erodibility (wind and water erosion), slope length and slope gradient, vegetational cover, and the kind of conservation practice (Hudson, 1976). Because sandy soils have a single grain structure, are non-sticky, non-plastic and non-coherent, they are highly susceptible to erosion and as such pose a special problem (Tayel and El-Hady, 1981).

Erosion of planted sites, especially where the vegetation has yet to become established, remains a serious problem within sand dune sites. Straw mulches are frequently used to control erosion, but are not thoroughly satisfactory. They are expensive, not available, and in some instances, cannot be used because of slope steepness (Mausbach and Shrader, 1975). Therefore, the use of soil chemical stabilizers as a replacement for the straw in the primary stages of sand dune stabilization by vegetation could be of great interest. Soil chemical stabilizers in the form of emulsions or solutions have been used to stabilize the soil structure in order to prevent or slow down water erosion or wind erosion while the vegetation cover is being established (Armbrust and Dickerson, 1971; Blavia et al., 1971;

Gabriels, 1976; and Lenvain et al., 1976). In order to control soil erosion, sandy, sandy loam, and calcareous soils from Egypt have been treated with bituminous emulsion, PVAc and PAM at different application rates (Tayel et al., 1981). It was found that soil conditioning increased the stability of aggregates larger than 0.25 mm and 0.84 mm in diameter. The erosion index increased and soil erosion decreased with increasing application rate. The response to conditioner treatments varied with the soil type, conditioner used and the application rate.

In order to test the effectiveness of the chemical stabilizers being used in this study, a series of simulation experiments were designed whereby samples of the various treatments were subjected to wind and water eroding agencies.

7.2 Effect of Soil Chemical Stabilizers on Soil Wind Erosion

7.2.1 Theoretical Basis

Wind acts on many soils by removing the finer fractions (clay and silt) and leaving the coarser ones (sand and gravel) behind (Daniel, 1938; Chepil, 1957; and Lyles, 1975). For example, Chepil (1949) reported that a loamy sandy soil from Canada under virgin conditions actually lost all its silt and clay in less than 60 years. He also noted that sandy loams, which had gained about 15 percent sand in the top 4 inches during the same period, would become sand dunes within 150 years of cultivation (assuming no change in cultural practices).

The sensitivity of soil towards wind erosion (soil erodibility) varies as a function of one or more of the following factors (De Boodt and De Vleeschauwer, 1981):-

1. Air-current: air speed, turbulence, density of the air as influenced by pressure, temperature, relative humidity and viscosity.
2. Soil: roughness, coverage, obstacles, obstructions, temperature, topography.
3. Soil structure stability: content of organic matter, CaCO3, Fe(OH)3, specific

weight and moisture content.

In all the above cases a change in the 'state' of the factor either increase or reduce the likelihood of the soil eroding eg. sandy soils are much more erodible when dry than wet.

Pasak (1974) considered that soil aggregates > 0.8 mm in diameter are sufficiently resistant to the erosive effect of wind.

The ability of various soil conditioners to reduce or control wind erosion has been tested in the field or by using windtunnel, by many workers (Chepil, 1955; Chepil et al., 1963b; Rostler and Kunkel, 1964; Lyles et al., 1969; and Armbrust and Dickerson, 1971).

A styrene-butadine latex in mineral oil liquid material was developed by an English company and tested throughout the world on sandy soils and dune sands (Haas and Steer, 1964; Simmons and Armstrong, 1965; and Weymouth, 1967). Tests indicated that 630 l ha^{-1} of 30% solids of 9:1 oil/rubber blend was ideal to control wind erosion.

Armbrust (1977) indicated that ammonium lignin sulfonate, sodium silicate, calcium chloride, and sodium silicate-calcium chloride mixtures also were effective against wind erosion until the first rain, when the materials dissolved and left the soil surface. Gelatinized starch decomposed rapidly after the rain and produced a more erodible surface than the original untreated surface, such materials are therefore of little use.

In a windtunnel experiment, De Boodt and De Vleeschauwer (1981) found that the threshold values at which sand movement was initiated at a height of 2 m were 23; 35; 50 and 60 km hr^{-1} for the control; netting overlay; PAM 10 gm m^{-2} and PAM 20 gm m^{-2} respectively. While, the sand loss measured for different windspeeds (at a height of 2 m) and different chemical treatments were 28.3; 0.0; 0.0 kg hr^{-1} when the windspeed was 22 km hr^{-1} and 5.2; 0.0; 0.0 km hr^{-1} when the windspeed was 17 km hr^{-1} for the control; PAM and bitumen treatments

respectively.

Because soil wind erosion can be described as a surface phenomenon (De Boodt and De Vleeschauwer, 1981); sand erosion can be tested out under laboratory conditions by using windtunnels. In the current study, a windtunnel capable of producing windspeeds of 1.5 m sec^{-1} to 30 m sec^{-1} was used to find out the effect of various chemical stabilizers (table 4.2) on sand erosion of Druridge Bay dunes sand by wind.

7.2.2 Techniques, Materials and Methods

300 gms samples of air-dry Druridge Bay dune sand were put in rhombohedral trays prepared especially for the windtunnel tests, such that the sand surface area in each tray was 100 cm^2 (figure (7.1). All the stabilizers - PVA1 (0.2% and 0.4%); PVA2 (0.2% and 0.4%); PEG3 (0.2% and 0.4%); PEG4 (0.2% and 0.4%); V1 (0.05 and 0.10 l m^{-2}); V2 (0.05 and 0.10 l m^{-2}); V3 (0.05 and 0.10 l m^{-2}); F.E. (0.2 and 0.4 l m^{-2}); B.E. (0.5 and 1.0 l m^{-2}); Aq1 (0.33% and 0.66%); and Aq2 (200 and 250 gm m^{-2}) were poured onto the sand samples at a rate equivalent to 6.0 l m^{-2}. Control samples were treated with similar volumes of distilled water. All samples were then air dried for 48 hrs before being tested. Three replicates of each treatment were tested.

A windtunnel system (figure 7.2) manufactured by (Plint and Partners Ltd. Engineers, Fishpond Road, Wokingham RG11 2QG, Berks, England) was used to simulate the effect of wind on sand particle movement over the stabilized and the control sand surfaces. The windspeed was controlled by supplying variable voltages to the 20 hp, C284 AC motor with maximum RPM of 1455 giving a maximum air speed with a 60 cm fan of 30 m sec^{-1}.

Three sand samples were placed on an adjustable table capable of being inclined from 0^o to 45^o. The tested samples were placed at inclination of 0, 15 and 30 degrees facing in to the wind.

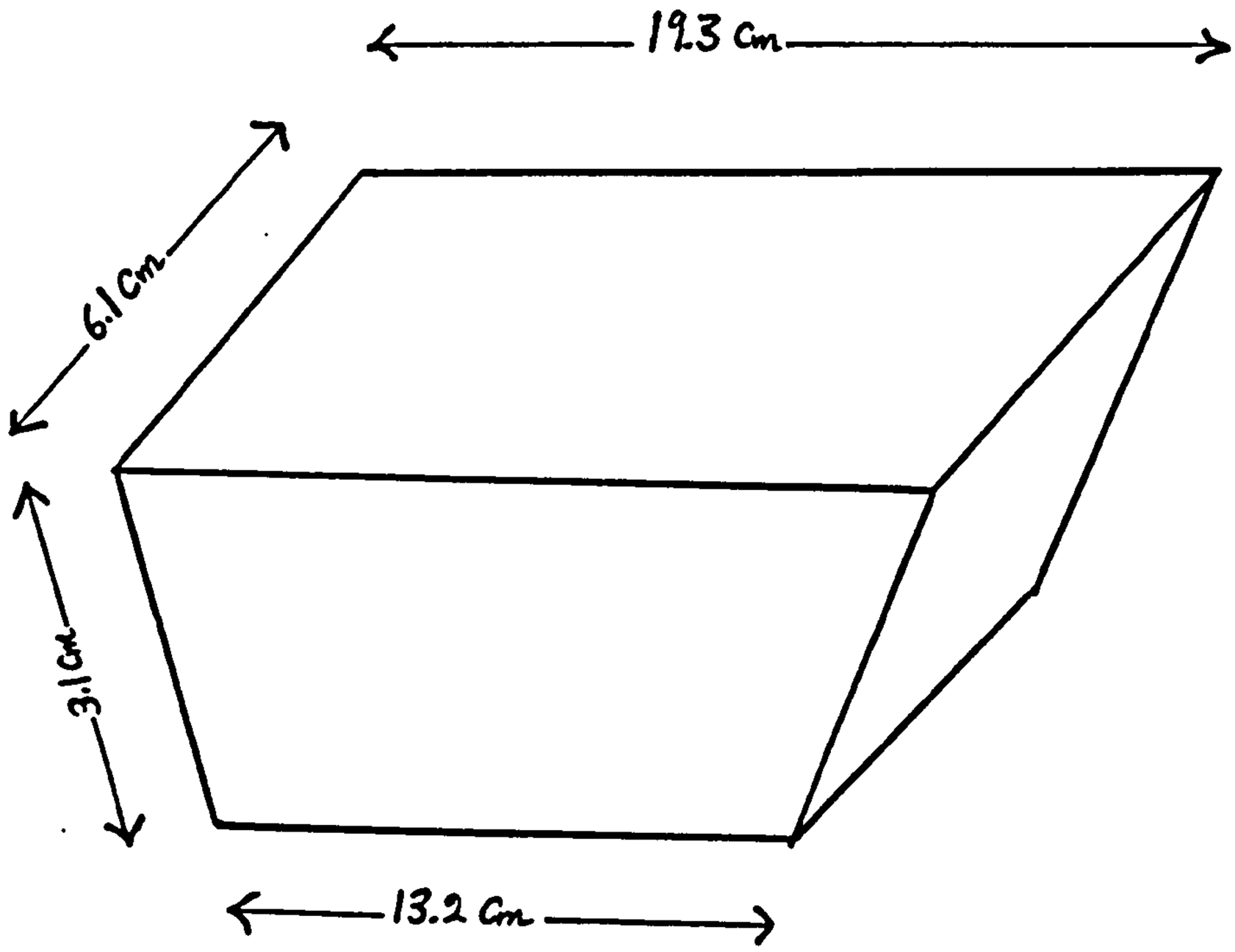


Figure 7.1: Diagram of the Tray Used in the Erosion Experiments.

This study aimed to investigate the following points:-

1. Threshold values at which sand movement will be initiated.
2. Sand loss measurements under the effect of different windspeeds (15 and 25 m sec^{-1}). Speed of 15 m $sec^{-1}$was selected as it is an occasional occurring windspeed at Druridge Bay. Whilst, the 25 m sec^{-1} speed represented the maximum windspeed recorded over a two year period (1988 and 1989) at the Northumberland Wildlife Trust, Hauxley Nature Reserve, Low Hauxley, Amble; a site close to the field study sites in the Druridge sand dunes.
3. Sand loss measurements from the different slope indinations used i.e. 0^o, 15^o and 30^o. According to Bagnold (1941) sand dune slopes never exceeded 34^o, whilst the maximum slope recorded during this study at Druridge Bay was 32^o. Thus 30^o is close to the upper limit of slope stability in non-stabilized dune sands.

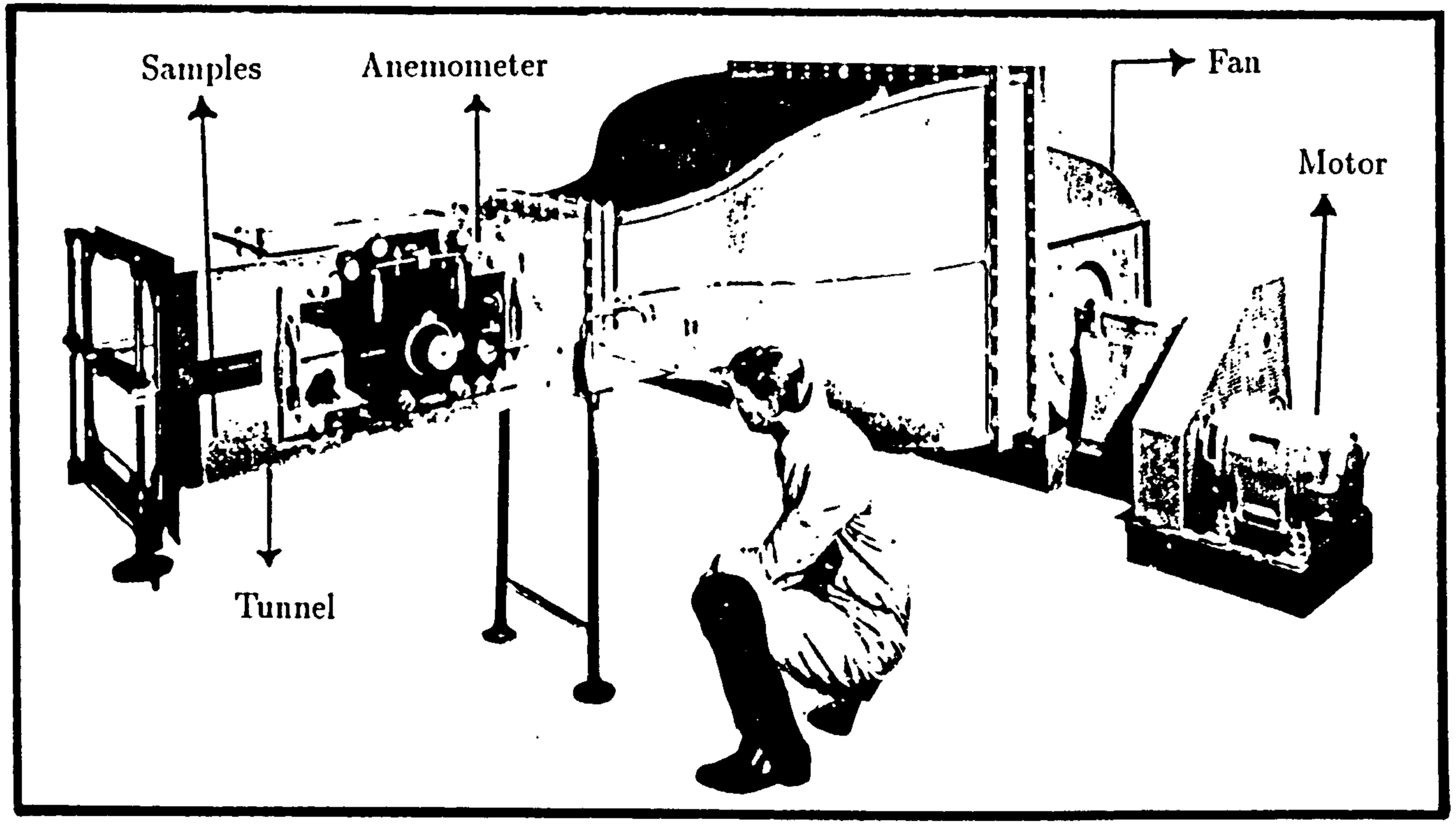


Figure 7.2: The Windtunnel System Used in the Study.

7.2.3 Results and Discussions

1. Experiment No. 1:

In this experiment, samples of a slope 0^o were exposed to windspeeds of 15 and 25 m sec^{-1} for 10 minutes. Because of the high surface erosion, the control samples were exposed to the wind for just 2 minutes when the windspeed was 25 m sec^{-1}, as the whole sample was removed within 10 minutes.

The threshold values at which sand movement was initiated, and the rate of sand erosion (%) at both 15 m sec^{-1} and 25 m sec^{-1} windspeeds were measured (table 7.1).

Results of this test indicate that no wind erosion occurred from any of the treated sand samples under the effect of either the 15 or 25 m sec^{-1} windspeeds. Whilst, the mean rate of erosion from the control samples were (46.1%) after 10 minutes at 15 m sec^{-1} and (83.8%) after only two minutes of exposure to the 25 m sec^{-1} wind.

2. Experiment No. 2:

Experiment 1 was repeated, but this time the samples were inclined at an angle of 15^o into the wind, and 10 minute wind runs at speeds of 15 and 25 m sec^{-1} applied. As in the case of the first experiment, the control samples were completely removed after 10 minutes at 25 m sec^{-1}.

The threshold values at which sand movement was initiated, and the rate of sand erosion (%) at both 15 m sec^{-1} and 25 m sec^{-1} windspeeds are illustrated in table 7.2. Table 7.2 shows that, no wind erosion occurred from any of the treated sand samples at a windspeed of 15 m sec^{-1}. Whilst, the control lost 50.0% of its total weight.

At 25 m sec^{-1} windspeed, samples treated with PVA1 (0.2% and 0.4%); V2 (0.1 l m^{-2}); V3 (0.05 and 0.10 l m^{-2}); F.E. (0.2 and 0.4 l m^{-2}); B.E. (0.5 and 1.0

Table 7.1: Rates of Sand Erosion (%) of Horizontal Samples at Windspeeds 15 m sec^{-1} and 25 m sec^{-1} After 10 Minutes of Exposure.

Treats	Conc.*	Threshold Values m sec^{-1}	Rate of Sand Erosion (%) at Windspeeds 15 m sec^{-1}	25 m sec^{-1}
PVA1	0.2%	N. E.	N. E.	N. E.
	0.4%	N. E.	N. E.	N. E.
PVA2	0.2%	N. E.	N. E.	N. E.
	0.4%	N. E.	N. E.	N. E.
PEG3	0.2%	N. E.	N. E.	N. E.
	0.4%	N. E.	N. E.	N. E.
PEG4	0.2%	N. E.	N. E.	N. E.
	0.4%	N. E.	N. E.	N. E.
V1	0.05 l m^{-2}	N. E.	N. E.	N. E.
	0.10 l m^{-2}	N. E.	N. E.	N. E.
V2	0.05 l m^{-2}	N. E.	N. E.	N. E.
	0.10 l m^{-2}	N. E.	N. E.	N. E.
V3	0.05 l m^{-2}	N. E.	N. E.	N. E.
	0.10 l m^{-2}	N. E.	N. E.	N. E.
F.E.	0.2 l m^{-2}	N. E.	N. E.	N. E.
	0.4 l m^{-2}	N. E.	N. E.	N. E.
B.E.	0.5 l m^{-2}	N. E.	N. E.	N. E.
	1.0 l m^{-2}	N. E.	N. E.	N. E.
Aq1	0.33%	N. E.	N. E.	N. E.
	0.66%	N. E.	N. E.	N. E.
Aq2	200 gm m^{-2}	N. E.	N. E.	N. E.
	250 gm m^{-2}	N. E.	N. E.	N. E.
Control		11.50	46.05	83.76**

* All (%) are on the base of air-dry sand; N. E. = No Erosion.

** After 2 minutes - all the sample had been removed within 10 minutes.

Table 7.2: Rates of Sand Erosion (%) at 15° Inclination at Windspeeds 15 m sec^{-1} and 25 m sec^{-1} After 10 Minutes of Exposure.

Treats	Conc.*	Threshold Values m sec^{-1}	Rate of Sand Erosion (%) at Windspeeds 15 m sec^{-1}	25 m sec^{-1}
PVA1	0.2%	N. E.	N. E.	N. E.
	0.4%	N. E.	N. E.	N. E.
PVA2	0.2%	25	N. E.	0.40
	0.4%	25	N. E.	0.31
PEG3	0.2%	25	N. E.	0.72
	0.4%	25	N. E.	0.53
PEG4	0.2%	25	N. E.	0.94
	0.4%	25	N. E.	0.84
V1	0.05 l m^{-2}	25	N. E.	0.80
	0.10 l m^{-2}	25	N. E.	0.48
V2	0.05 l m^{-2}	24	N. E.	0.93
	0.10 l m^{-2}	N. E.	N. E.	N. E.
V3	0.05 l m^{-2}	N. E.	N. E.	N. E.
	0.10 l m^{-2}	N. E.	N. E.	N. E.
F.E.	0.2 l m^{-2}	N. E.	N. E.	N. E.
	0.4 l m^{-2}	N. E.	N. E.	N. E.
B.E.	0.5 l m^{-2}	N. E.	N. E.	N. E.
	1.0 l m^{-2}	N. E.	N. E.	N. E.
Aq1	0.33%	N. E.	N. E.	N. E.
	0.66%	N. E.	N. E.	N. E.
Aq2	200 gm m^{-2}	N. E.	N. E.	N. E.
	250 gm m^{-2}	N. E.	N. E.	N. E.
Control		11.30	50.04	89.51**

* All (%) are on the base of air-dry sand; N. E. = No Erosion.

** After one minute - all the sample had been removed within 10 minutes.

l m^{-2}); Aq1 (0.33% and 0.66%); and Aq2 (200 and 250 gm m^{-2}) remained stable against wind erosion, and did not loose any sand. All the remaining treatments i.e. PVA2 (0.2% and 0.4%); PEG3 (0.2% and 0.4%); PEG4 (0.2% and 0.4%); V1 (0.05 and 0.10 l m^{-2}) and V2 (0.05 l m^{-2}) were slightly eroded, losing 0.40%; 0.31%; 0.72%; 0.53%; 0.94%; 0.84%; 0.80%; 0.48% and 0.93% respectively. The control lost 89.5% of its total weight after only one minute, and was completely removed after 10 minutes.

From table 7.2 it can be seen that, (i) the rate of sand erosion decreased as the chemical application concentrations increased; (ii) erosion from all chemical treatments under 25 m sec^{-1} windspeed were negligible when compared with the control which lost 89.5% of its weight within only one minute.

3. Experiment No. 3:

The previous experiments were repeated with the samples placed at an inclination of 30^{o}, as previously the control samples were totally eroded within the 10 minutes test run at 25 m sec^{-1} (table 7.3).

From table 7.3 it is evident that, all chemical treatments could withstand erosion at windspeeds of 15 m sec^{-1}. Whilst, the control lost 52.4% of its total weight after 10 minutes.

At 25 m sec^{-1} windspeed, the PVA1 (0.2% and 0.4%); V2 (0.10 l m^{-2}); V3 (0.05 and 0.10 l m^{-2}); F.E. (0.2 and 0.4 l m^{-2}); B.E. (0.5 and 1.0 l m^{-2}); Aq1 (0.33% and 0.66%) and Aq2 (200 and 250 gm m^{-2}) treated samples resisted erosion completely. The remaining treatments: PVA2 (0.2% and 0.4%); PEG3 (0.2% and 0.4%); PEG4 (0.2% and 0.4%); V1 (0.05 and 0.10 l m^{-2}) and V2 (0.05 l m^{-2}) lost respectively, 0.46%; 0.38%; 0.97%; 0.90%; 1.06%; 0.84%; 0.99%; 0.54% and 1.06% of their total weight after 10 minutes of exposure. Whilst, the control lost 98.5% of its total weight after only one minute and was completely removed after 10 minutes.

Table 7.3: Rates of Sand Erosion (%) of Samples at 30° Inclination at Windspeeds 15 m sec^{-1} and 25 m sec^{-1} After 10 Minutes of Exposure.

Treats	Conc.*	Threshold Values m sec^{-1}	Rate of Sand Erosion (%) at Windspeeds 15 m sec^{-1}	25 m sec^{-1}
PVA1	0.2%	N. E.	N. E.	N. E.
	0.4%	N. E.	N. E.	N. E.
PVA2	0.2%	25	N. E.	0.46
	0.4%	25	N. E.	0.38
PEG3	0.2%	25	N. E.	0.97
	0.4%	25	N. E.	0.90
PEG4	0.2%	25	N. E.	1.06
	0.4%	25	N. E.	0.84
V1	0.05 l m^{-2}	25	N. E.	0.99
	0.10 l m^{-2}	25	N. E.	0.54
V2	0.05 l m^{-2}	25	N. E.	1.06
	0.10 l m^{-2}	N. E.	N. E.	N. E.
V3	0.05 l m^{-2}	N. E.	N. E.	N. E.
	0.10 l m^{-2}	N. E.	N. E.	N. E.
F.E.	0.2 l m^{-2}	N. E.	N. E.	N. E.
	0.4 l m^{-2}	N. E.	N. E.	N. E.
B.E.	0.5 l m^{-2}	N. E.	N. E.	N. E.
	1.0 l m^{-2}	N. E.	N. E.	N. E.
Aq1	0.33%	N. E.	N. E.	N. E.
	0.66%	N. E.	N. E.	N. E.
Aq2	200 gm m^{-2}	N. E.	N. E.	N. E.
	250 gm m^{-2}	N. E.	N. E.	N. E.
Control		11.30	52.38	98.53**

* All (%) are on the base of air-dry sand; N. E. = No Erosion.

** After one minute - all the sample had been removed within 10 minutes.

As in the case of the second experiment, it is possible to conclude that: (i) the rates of sand erosion increases as the chemicals concentrations decreases; (ii) when compared with the control, the 10 minutes loss from the treated samples can be considered negligible.

4. Experiments No. 4 and 5:

Due to the extremely high resistance of Aq1 (0.33% and 0.66%); Aq2 (200 and 250 gm m^{-2}); F.E. (0.2 and 0.4 l m^{-2}) and B.E. (0.5 and 1.0 l m^{-2}) treatments to wind erosion as indicated in the previous three experiments, two further experiments using only these chemicals were performed:-

1. Samples were inclined at 30^o and were attacked by blowing 2 kgm of air-dry sand at them at a windspeed of 25 m sec^{-1}.
2. Samples tilted at 30^o were continuously exposed to 25 m sec^{-1} windspeed for 10 hours.

The results showed the following:-

1. The control lost 98.5% of its total weight in the first minute of exposure in both trials, and was completely removed after few minutes.
2. All the treated samples withstood both sand attack and prolonged exposure to high windspeeds. No sand was lost from any treated sample under either set of conditions.

7.2.4 The Conclusions

From the above experiments the following conclusions can be made:

1. The sand samples at high slope angles to the wind are more vulnerable to wind erosion. The rate of erosion (%) at both windspeeds (15 and 25 m sec^{-1}) from the treated and untreated samples can be ranked as follows: slope 30^o > slope 15^o > slope 0^o.
2. The threshold values at which sand movement was initiated from the control

samples at both 15^o and 30^o slopes were slightly lower than at 0^o slope. They were respectively 11.3 m sec^{-1} and 11.5 m sec^{-1}.

3. Where treated samples showed signs of erosion this always occurred first in the samples treated with the lowest concentration of chemical.
4. Compared with the control, sand erosion from all the treated sand samples could be considered negligible over the 10 minute period.
5. Of the treatments used, Aq1 (0.33% and 0.66%); Aq2 (200 and 250 gm m^{-2}); F.E. (0.2 and 0.4 l m^{-2}); and B.E. (0.5 and 1.0 l m^{-2}) were found to be extremely stable against wind erosion and did not loose any of their sand even under the most extreme cases: (i) samples placed at 30^o slope and were attacked by the blowing 2 kgm of air-dry sand under the effect of 25 m sec^{-1} windspeed; (ii) samples placed at 30^o slope and were continuously exposed to the windspeed 25 m sec^{-1} for 10 hours.

7.3 Effect of Soil Chemical Stabilizers on Soil Water Erosion

7.3.1 Theoretical Basis

Laboratory rainfall simulators have been used by a number of workers to assess the effectiveness of a range of soil conditioners (Blavia et al., 1971; Gabriels et al., 1973; and Pauwels et al., 1976). Mannering and Meyer (1963); Meyer et al. (1972); and Gabriels (1976a) have attempted to test stabilizers under field conditions.

Blavia et al. (1971) found that superfloc; PVA; VAMA and potassium silicate were the most effective of thirteen chemical materials sprayed on clods to increase soil resistance to erosion by rainfall.

Moldenhauer and Gabriels (1972) indicated that PVA was very effective in controlling water erosion both in the laboratory and in the field, while, soil loss rates from the samples treated with PVAc or vinyl acetate maliec acid were as

great as or greater than the control at the end of 90 minutes.

Rainfall simulator tests indicated that the energy required to initiate runoff was much greater on Iowa State subsoil clods treated with two polyvinyl alcohols (PVA) and a polyacrylamide (PAM) than on untreated clods (Mausbach and Shrader, 1975). Previously, Gabriels et al. (1973) had shown that the same two polymers (PVA and PAM) were effective in stabilizing the surface clods from Iowa State against rainfall energy received between a seeding and the establishment of a complete cover from the seedlings.

In another rainfall simulator experiment, PAM; PVA; PVAc and asphalt emulsion sprayed at different rates on the surface layer of dune sand and silt loam soil aggregates were effective in reducing water erosion (Gabriels and De Boodt, 1975). They found that small quantities of bituminous emulsions (0.35 l m^{-2}) highly diluted with water can be used as a mulch on sand surfaces. The high dilution enables the bitumen micelles to migrate and penetrate deeper under the sand surface, linking sand particles together after drying.

Again in a rainfall simulator experiment with rain intensities (6.5 - 64.5 mm hr^{-1}), Gabriels et al. (1974) found that PVAc; PAM (with cross-linker) and an asphalt emulsion sprayed on the surface or incorporated with the sand at optimal rates, reduced appreciably the side splash erosion of Belgian seacoast dune sand.

De Vleeschauwer and Gabriels (1976) reported that a treatment with 20 gm m^{-2} of PAM in strips either along the direction of the slope, or across the direction of the slope, decreased significantly splash erosion, water runoff and soil loss.

The applications of PAM solution and bitumen emulsion at the levels (0.16% and 1.25% on soil air-dry weight basis) respectively, to several soils of different texture, were effective in stabilizing the surfaces against the effects of raindrop impact (Pla, 1975). Bituminous emulsion seemed to be most effective.

A high concentration of bitumen emulsion when sprayed on small aggregates of Clarion loam soil (2 - 8 mm) showed some effectiveness in decreasing total soil

loss (Gabriels, 1972).

De Boodt (1975) illustrated a highly significant reduction in cumulative soil loss as a function of the rainfall in Puchong area, Malaysia, when the soil surface was treated with bitumen; planted with a leguminous *Pueraria phaseloides*; or the combination of the chemical and the plant, compared to the untreated field plots.

In Ivory Coast, West Africa, an artificial mulch of curasol at (60 gm l^{-1} m^{-2}) tested during 3 years on three sets of duplicate plots, reduced the annual erosion by 40% to 70% of check plots, and the runoff by 25% to 55% (Roose, 1975).

In a rainfall simulator study, butadiene-styrene copolymer and polyurethane were shown to be able to prevent or slow down water erosion from a dune sand surface or a clayey soil surface when applied at optimal amounts and dilution rates (Gabriels, 1976b).

Kouznetsov and Grygoriev (1976) found that the intensity of loamy soil loss in irrigated furrows treated with hydrolysed polyacrylonitrile (k-4) polymer was 9 - 10 times lower than in untreated furrows, when water velocity was 0.10 - 0.13 m sec^{-1}.

Following the above review, an experiment was developed to test the resistance of the various stabilizers under investigation to water erosion. Since the wind tunnel studies indicated that most chemical materials were able to withstand wind erosion, it was hoped that rainfall simulator experiments would narrow the range of chemicals for field testing.

7.3.2 Techniques, Materials and Methods

In this study, simulated rainfall was applied using a water drop applicator fixed at 3 m above the samples. The applicator was flexible and was connected to a shaker to shake it slightly in order to change the point of impact of the rain drops. 300 gm samples of air-dry dune sand were placed in the trays used for the windtunnel experiments, and the surfaces were treated with the various chemicals

under investigation, all were diluted to give the equivalent application rate of 6.0 l m^{-2}. After the treatment, the sand surfaces were allowed to dry for 48 hrs. The sand samples in the trays were inclined at an angle of 30^o and exposed to a simulated rainfall rate equivalent to 110 mm hr^{-1} for 20 minutes (Mausbach and Shrader, 1975). This rate in fact is equivalent to 37 mm per 20 minutes. From the original meteorological data collected for the Druridge Bay area it is found that the highest recorded daily precipitation rates during the years 1988 and 1989 were 24.0 mm; 36.0 mm and 54.0 mm. Intense precipitation can occur and the above volumes can fall in a very short time (a few minutes) resulting in a great deal of damage to the surface layer. The rate chosen for this experiment (i.e. 37 mm per 20 minutes) equates with the mean of the three highest rainfall events recorded at Druridge Bay and assumes that they occurred in 20 minutes rather than 24 hrs. Whilst, this study attempted to create rainfall amounts similar to extreme events that could occur at Druridge Bay, in order to find out the effect of the rainfall on the treated and untreated Druridge Bay sand surfaces, no attempt was made to measure the size of water drops.

At the end of the test, sand loss from each tray was measured by drying the samples in the oven at 60 ^oC and calculating the differences between the initial and the final weights.

7.3.3 Results and Discussions

Figure 7.3 and table 7.4 summarises the results of the simulation test.

1. Compared to the control loss of 64.16%, all treatments showed some reduction in sand loss. The most effective treatments were the higher concentrations of Aq1; Aq2; B.E.; PVA2; F.E.; V3 and V2 all of which had < 1% loss with the first 3 having 0% loss. At the lower concentration all showed some loss. The remaining chemicals V1; PEG3; PEG4 and PVA1 were not very effective in reducing erosion.

FIG. 7.3: EFFECT OF VARIOUS CHEMICAL STABILIZERS ON THE STABILITY OF DRURIDGE BAY SAND AGINST WATER EROSION

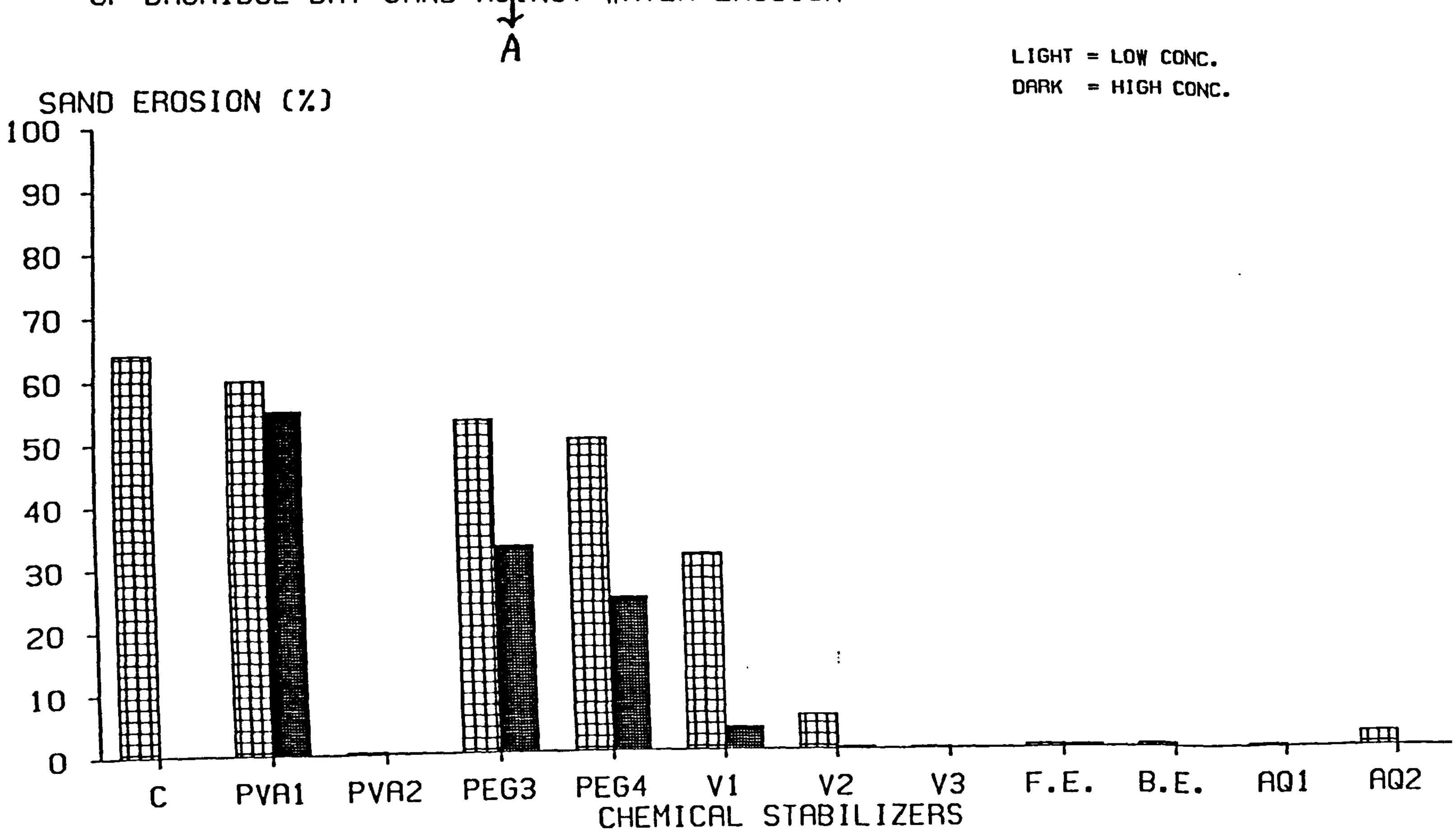


Table 7.4: Rates of Sand Erosion (%) Under the Effect of a Simulated Rainfall Rate Equivalent to 110 mm hr^{-1} for 20 Minutes.

Treats	Conc.*	Rate of Sand Erosion (%)
PVA1	0.2%	60.00
	0.4%	55.17
PVA2	0.2%	0.32
	0.4%	0.11
PEG3	0.2%	53.42
	0.4%	33.19
PEG4	0.2%	50.19
	0.4%	24.68
V1	0.05 l m^{-2}	31.52
	0.10 l m^{-2}	3.49
V2	0.05 l m^{-2}	5.49
	0.10 l m^{-2}	0.24
V3	0.05 l m^{-2}	0.22
	0.10 l m^{-2}	0.05
F.E.	0.2 l m^{-2}	0.47
	0.4 l m^{-2}	0.31
B.E.	0.5 l m^{-2}	0.46
	1.0 l m^{-2}	0.00
Aq1	0.33%	0.24
	0.66%	0.00
Aq2	200 gm m^{-2}	2.28
	250 gm m^{-2}	0.00
Control		64.16

* All (%) are on the base of air-dry sand.

2. Sand surface erosion decreased as the chemical concentration increased.
3. A close inspection of the samples revealed that a thin surface crust (about 2 mm thick) had formed as a result of applying the following chemicals PVA1; PVA2; PEG3; PEG4; V1; V2; V3 and Aq1 (0.33%); and it was this crust that was responsible for the reduction in water erosion. Any damage in this thin surface layer exposed the loose sand beneath to the raindrop attack. In the case of the remaining chemicals i.e. Aq1 (0.66%); B.E. (1.0 and 0.5 l m^{-2}); F.E. (0.4 and 0.2 l m^{-2}) and Aq2 (250 and 200 gm m^{-2}), a hard layer of about (16 mm thick) had formed at the surface, this greatly increasing the resistance of the soil to erosion.
4. As length of time of exposure is critical in water erosion as its effect is cummulative, and since the experiment was conducted for only 20 minutes then the most useful stabilizers are those which show no loss in that time i.e. higher concentrations of Aq1; Aq2 and B.E.

7.4 The Conclusions

Despite the findings of other workers, V1; PEG3; PEG4 and PVA1 proved unsatisfactory as stabilizing agents against both wind and water erosion. Of the remaining chemicals, PVA2; Aq1 (0.33%); V3 and V2 performed rather better, however noticeable erosion occurred under heavy rainfall. Furthermore, in the aggregate stability tests (chapter 5) PVA2; V3 and V2 performed very badly showing no long term stability.

Thus of the chemicals tested in the erosion experiments only Aq1 (0.66%); B.E. (1.0 and 0.5 l m^{-2}); Aq2 (250 and 200 gm m^{-2}) and F.E. (0.4 and 0.2 l m^{-2}) can be recommended. As Aq2 was only made available late in the research period, only Aq1; B.E. and F.E. were used in the large term controlled field trials.

CHAPTER 8

EFFECT OF BITUMEN, AQUAPOL AND FERQUATAC CHEMICALS ON THE STABILIZATION OF DRURIDGE BAY SAND DUNES

8.1 Introduction

Druridge Bay Country Park (between latitudes 94° and 102°) north, is managed by Northumberland County Council through the National Park and Countryside Department and offers to the visitor opportunities for a broad range of outdoor recreational pursuits. It covers 131 hectares and includes a large man-made lake, open grassland, woodland and 5 km of coastal dunes with a magnificent sandy beach. Northumberland County Council took over the site in March 1986 and have carried out a development programme including grassland establishment, access to the beach, drainage, landscaping and in 1988 the erection of the Visitor Centre building. Therefore, the beach is one of the many popular resort beaches within the North-East part of England*.

Sand particles in these dunes as in many other coastal sand dunes are formed due to the effect of both sea water movement and wind erosion which causes the accumulation of huge amounts of sand. In Druridge Bay this has resulted in the formation of one line of longitudinal coastal sand dunes almost parallel to the sea shore (figure 8.1). The height of these dunes varies and ranges between < 3 m and 35 m (photo 8.1). The slopes of faces also vary and with the highest dunes sloping up to 32°.

The dunes have been designated a Site of Special Scientific Interest (SSSI) by the Nature Conservancy Council because of the rich and diverse plant community found there. A survey carried out in the summer of 1989 revealed 283 species of

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* *Sand dunes at Druridge Bay are part owned by the Northumberland County Council and part owned by the National Trust.*

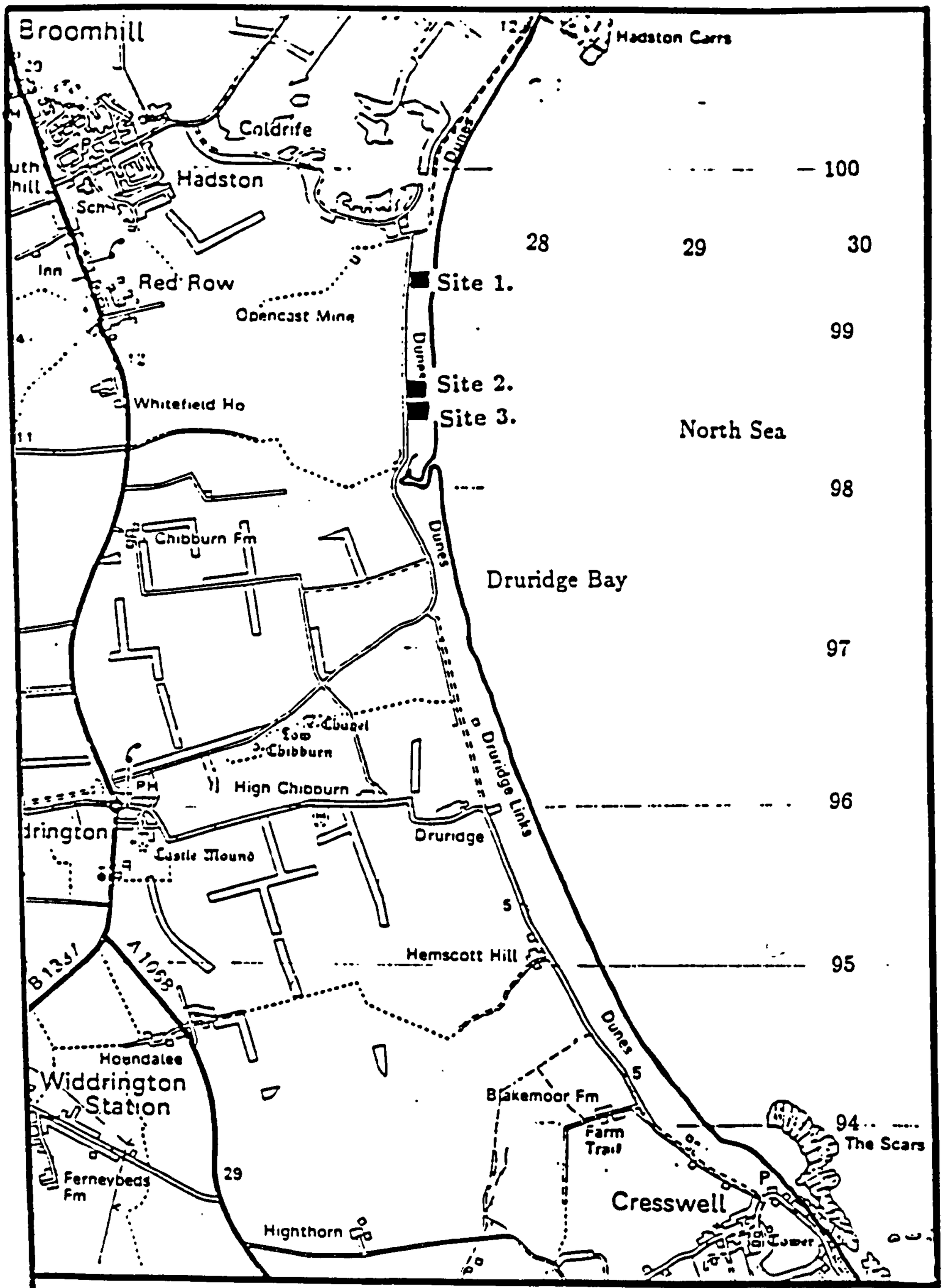
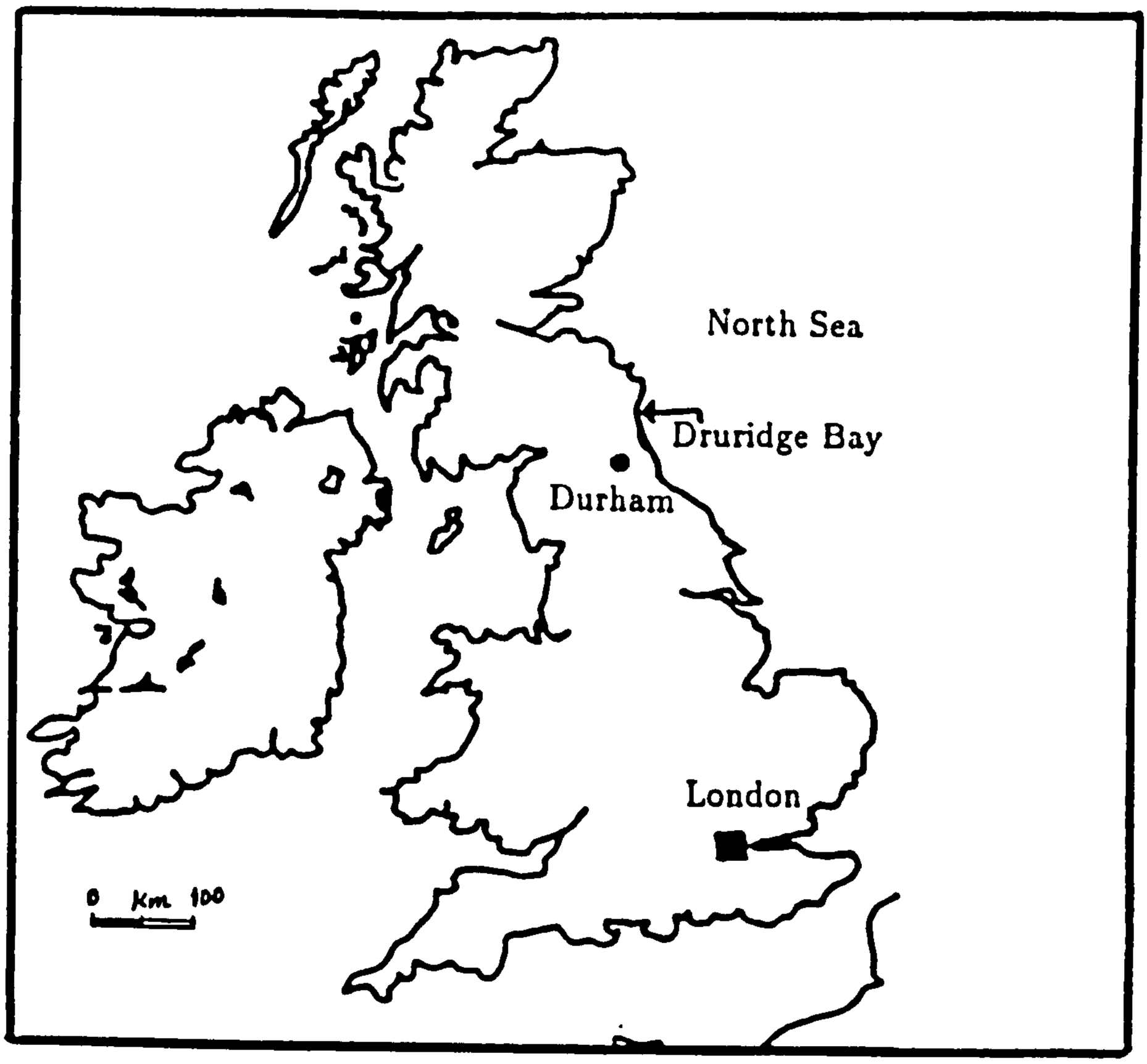
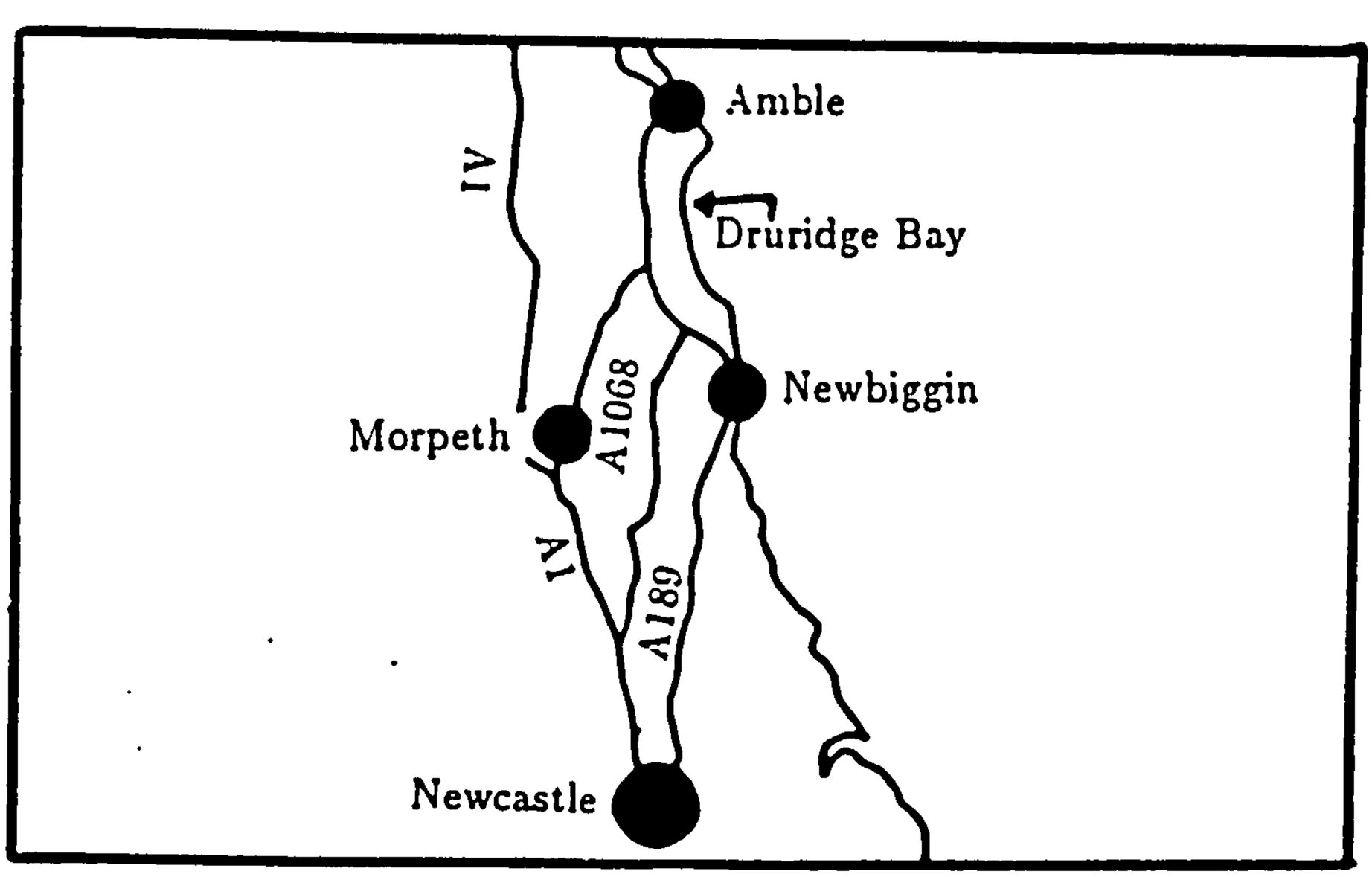


Figure 8.1a: The Map of Druridge Bay Area Indicating the Sand Dunes and the Positions of the Three Field Sites (Scale 1:50000).





Figures 8.1b and 8.1c: The Map of Great Britain indicating the Position of Druridge Bay Area and the Highways to Druridge Bay.

Plate 8.1: Druridge Bay Sand Dunes (Height Variation).

plants on the dunes.

Although most of the sand dunes at Druridge Bay are already stabilized mainly through marram grass plants, many other dunes are active, especially on the sea facing side, through wind erosion, water erosion and the activities of holiday makers. Any area of stable dunes are in delicate state of balance and readily erode if their protective vegetative cover is weakened or removed (Mitchell, 1974). Continued sand drift and sand removal if unchecked would result in lowering of the dunes height which would increase the risk of inundation of the low lying land behind the dunes. Therefore, both the National Trust and the Northumberland County Council have carried out some stabilization trials on the sand dunes at Druridge Bay using marram grass protected by dead tree branches. Some of these trials succeeded, but others failed due to high wind erosion in some cases and vandalism in others (photos 8.2 - 8.5).

The reason for choosing Druridge Bay as a field site for this study has already

Plate 8.2: The Stabilization of Sand Dunes at Druridge Bay Using Marram Grass Tillers Protected by Dead Tree Branches (September 1987).

Plate 8.3: Complete Destruction of the Above Mentioned Site Due to Vandalism and Wind Erosion.

Plate 8.4: The Stabilization of Sand Dunes at Druridge Bay Using Marram Grass Tillers Protected by Dead Tree Branches (1986 - 1990).

Plate 8.5: Complete Destruction of Another Planted-Fenced Site Due to Vandalism and Wind Erosion (1986 - 1987).

been discussed in chapter 4 section 4.2.

8.2 The Meteorological Data Collected from the Area - Some Statistical Analysis and Discussions

Climatic conditions play an important role in the formation, maintenance and destruction of sand dune systems both directly by causing erosion/accumulation and indirectly by influencing vegetation growth and soil formation.

The nearest meteorological station to the study site is at the Hauxley Nature Reserve, Low Hauxley, which is located at the northern end of Druridge Bay. For the purpose of this study an anemometer was added to their range of instruments to provide information on windspeeds. Table 8.1 lists both monthly and annual averages of maximum and minimum air-temperatures, soil temperatures at 5 cm, 10 cm and 20 cm depths, wet and dry bulb temperatures, windspeeds, precipitation, barometric pressure and humidity. Whilst, table 8.2 illustrates the frequencies of wind direction at Druridge Bay.

i. Air-Temperature:

The mean annual air-temperature is 9.11°C. The highest maximum temperatures are in June, July, August and September. They are respectively 16.23°C, 18.47°C, 19.49°C and 17.02°C (table 8.1). The coldest months are January, February, March, November and December with the minimum average air-temperatures 2.85°C, 1.58°C, 2.38°C, 2.32°C and 2.65°C respectively. From The original data, it is found that the maximum daily air-temperature was 24°C in both July and August 1989, whilst, the minimum daily air-temperature was (-5°C) in February 1989.

ii. Soil Temperature:

The annual average soil temperatures for the years 1988 and 1989 and at the depths 5 cm, 10 cm and 20 cm are respectively 9.31°C, 9.31°C and 9.57°C

Table 8.1 : Monthly and Annual Averages of the Meteorological Data at Druridge Bay (1988-1989).

Month	Air-Temperature (^{o}C)		Soil Temperature (^{o}C) at Depths			Windspeed m sec^{-1}
	Max.	Min.	5 cm	10 cm	20 cm	
Jan.	8.63	2.85	5.01	5.30	6.54	5.97
Feb.	8.67	1.58	4.32	4.42	5.00	8.31
Mar.	9.61	2.38	5.40	5.30	5.50	5.63
Apr.	10.11	3.24	7.10	7.07	7.19	3.36
May	13.69	5.51	10.75	10.25	10.30	2.98
June	16.23	8.08	13.54	13.55	12.94	3.44
July	18.47	10.00	15.14	14.95	14.88	3.19
Aug.	19.49	10.09	14.62	14.53	14.74	3.61
Seb.	17.02	8.44	12.75	12.83	13.02	3.98
Oct.	13.74	7.43	10.62	10.81	11.07	4.05
Nov.	9.99	2.32	6.92	7.06	7.65	4.34
Dec.	8.44	2.65	5.52	5.66	6.04	4.05
Annual Average	12.84	5.38	9.31	9.31	9.57	4.41

Table 8.1 (Continue)

Month	Wet Bulb (^{o}C)	Dry Bulb (^{o}C)	Precipitation (mm)	Barometric Pressure (mb)	Humidity (%)
Jan.	5.35	6.17	90.9	1003.5	86.0
Feb.	4.85	5.97	27.0	1000.0	81.0
Mar.	5.95	7.00	48.8	996.6	84.6
Apr.	7.27	8.46	28.0	1003.8	84.5
May	10.11	12.50	26.9	1009.9	84.1
June	11.50	14.19	28.7	1010.0	80.8
July	13.79	16.05	79.3	1004.8	85.1
Aug.	13.77	15.60	54.1	1001.1	82.1
Seb.	11.70	13.37	29.1	1006.3	81.9
Oct.	9.75	10.62	52.2	1001.4	87.6
Nov.	6.82	7.43	30.6	1004.7	85.5
Dec.	5.88	6.72	36.8	1004.1	82.7
Annual Average	8.90	10.34	532.4	1003.9	83.8

Table 8.2: Frequencies of Wind Direction at Druridge Bay

(Years 1988 and 1989)

Month	Average Frequencies of Wind Direction							
	N	NE	E	SE	S	SW	W	NW
Jan.	0.0	0.5	0.0	0.5	3.0	15.5	7.0	2.0
Feb.	1.5	0.0	0.0	0.0	2.5	9.5	6.5	4.5
Mar.	1.5	2.0	0.5	1.0	8.0	4.5	5.0	4.0
Apr.	2.5	4.0	4.0	4.0	2.0	3.0	3.0	2.5
May	3.5	4.5	3.5	4.0	2.5	3.0	3.5	1.5
June	7.0	6.0	1.5	2.0	4.0	2.0	3.0	1.5
July	5.5	1.5	1.5	1.5	3.0	7.5	3.5	3.0
Aug.	1.5	1.0	0.0	5.5	1.0	13.0	5.0	3.0
Seb.	1.5	2.0	0.0	1.0	2.0	8.5	9.0	3.5
Oct.	0.0	0.5	0.0	7.0	2.5	10.0	5.5	3.5
Nov.	0.5	4.0	2.5	3.5	1.0	8.0	6.0	1.5
Dec.	0.5	2.5	1.5	1.0	1.0	5.5	8.0	2.5
Annual Average	25.5	28.5	15.0	31.0	32.5	90.5	65.0	33.0

(table 8.1). The highest daily soil temperatures at the above mentioned depths are respectively 19.5°C, 17°C and 17°C in August 1988 and 1989. Soil temperatures at all depths are strongly connected to the daily air-temperatures. Increases in the air-temperature will increase the soil temperature at all depths, whilst the decreases will decrease the soil temperature.

iii. Windspeed and Direction:

The dominant wind direction in the Druridge Bay area is the South-West (90.5 times a year) followed by the West wind direction (65 times a year) (table 8.2). The most important factor however is the windspeed which directly influ-

ences rates of erosion. The annual average windspeed is 4.41 m sec^{-1} with the highest monthly average of 8.31 m sec^{-1} in February (table 8.1). From the original data for both years 1988 and 1989, the highest recorded windspeed was 25 m sec^{-1} in February 1988.

iv. Wet and Dry Bulb Temperatures:

The annual averages of both wet and dry bulbs for the years 1988 and 1989 are respectively 8.90°C and 10.34°C (table 8.1). From the original data for both years 1988 and 1989, it is found that the highest daily wet and dry bulbs are respectively 19.0°C and 24.0°C in August (1988 and 1989) and July 1989. Whilst, the lowest ones are respectively (-2°C) and (-2.5°C) in December 1989.

v. Precipitation:

Monthly precipitation averages for both years 1988 and 1989 range from 26.9 mm in May to 79.3 and 90.9 in July and January respectively (table 8.1). The annual average precipitation is 532.4 mm. The highest daily amounts in the two year period were 54 mm and 36 mm in January and July 1988 respectively. The annual rainfall showed enormous variation, 1988 was at least twice as much as in the year 1989. They were respectively 753.7 mm and 310.7 mm. Figure 8.2 illustrates the monthly precipitations of both 1988 and 1989 years.

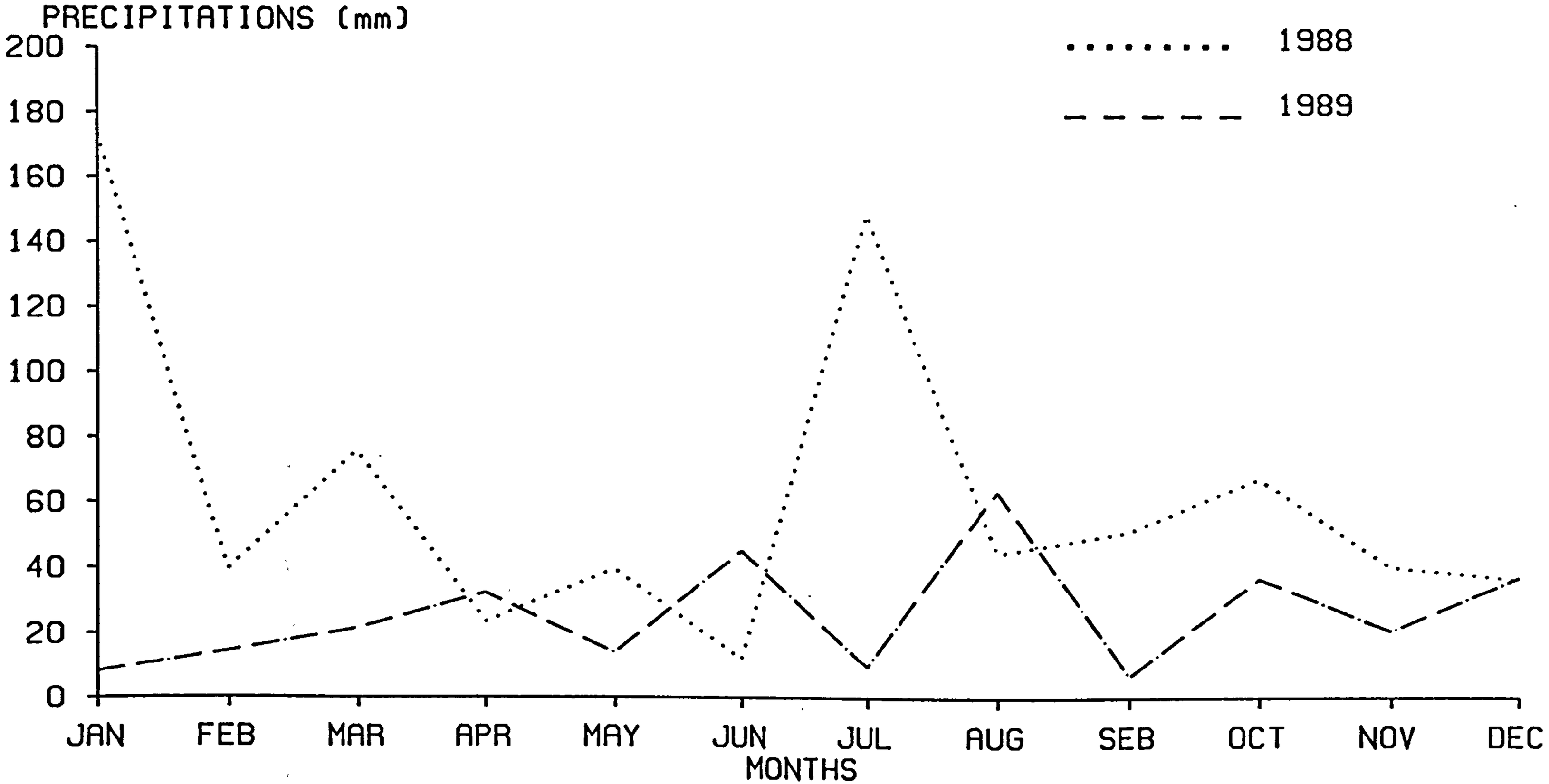
vi. Barometric Pressure:

The annual barometric pressure average is 1003.9 mb (table 8.1). The highest daily barometer pressure in both 1988 and 1989 years was 1034 in December 1988; whilst, the lowest was 943 in February 1989.

vii. Humidity:

The annual average relative humidity is 83.8% with the monthly averages ranging from 80.8% in June to 87.6% in October (table 8.1). The highest daily humidity was 100%, whilst the lowest one was only 40% in March 1988.

FIG. 8.2: MONTHLY PRECIPITATIONS OF THE YEARS 1988 AND 1989.



8.3 Experimental Design

In October 1988, three sites at Druridge Bay were chosen to be used for the field trials. Site 1 was 700 m south of the Visitor Centre building; whilst, both sites 2 and 3 were about 2 km south of the same building. Both sites 1 and 2 were south facing; whilst, site 3 was north facing. Their slopes were respectively 30^o, 32^o and 12^o - 15^o. All sites were well fenced, planted with marram grass (sites 1 and 3) and lyme grass (site 2). Photos (8.6 - 8.11) illustrate the three field sites before and after plantation*. Using the conclusions drawn as a result of laboratory, greenhouse and erosion tests (chapters 5 and 7), only the following chemicals were considered suitable for the field trials:-

1. Ferquatac emulsion RB50 (F.E.) 0.2 l m^{-2},
2. Ferquatac emulsion RB50 (F.E.) 0.4 l m^{-2},
3. Bitumen emulsion A1-50 (B.E.) 0.5 l m^{-2},
4. Bitumen emulsion A1-50 (B.E.) 1.0 l m^{-2},
5. Aquapol 3500-19 (Aq1) 0.66% (172 gm m^{-2}),
6. Aquapol 3500-19 (Aq1) 1.00% (260 gm m^{-2}),
7. Control,
8. At this time Aq2 was not available and was therefore not used in these field trials.

The soil chemical treatments were carried out between 10th November to 1st December 1988. All the chemicals were diluted with tap water to 6.0 l m^{-2}. The reason for using the Aq1 (1.0%), even though it was impermeable in the laboratory test, was that the infiltration rates on grasslands is substantially higher than the

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* *I am most grateful for the help given by Dr. Paul Morrison of Northumberland County Council who provided fencing and field assistants for the construction of the plots and planting of the marram and lyme grasses. The National Trust kindly allowed me to attend a conservation week during which I learnt their methods of planting and protecting sand dunes.*

Plate 8.6: Site 1 Before Plantation.

Plate 8.7: Site 1 After Plantation With Marram Grass Tillers.

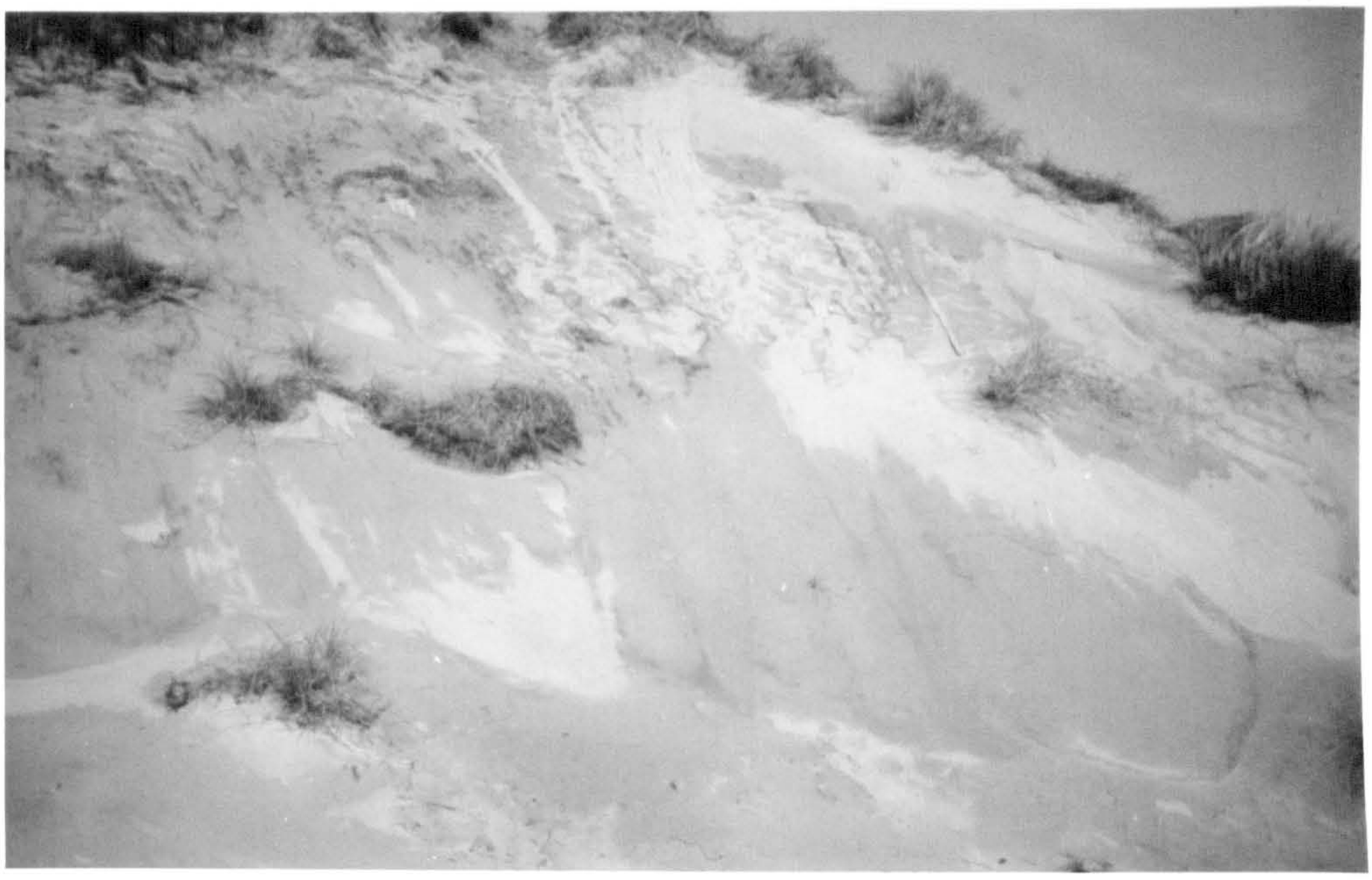


Plate 8.8: Site 2 Before Plantation.

Plate 8.9: Site 2 After Plantation With Lyme Grass Tillers.

Plate 8.10: Site 3 Before Plantation.

Plate 8.11: Site 3 After Plantation With Marram Grass Tillers.

bare untreated land (Michael, 1978).

Owing to the sloping conditions of the field sites, the experimental plan in each site was based on the completly randomized block design (CRBD) with each of the above mentioned 7 treatments replicated three times (Mead and Curnow, 1983) rather than a completly randomized design (CRD). The treatments were randomly distributed within three blocks in each site (figures 8.3 - 8.5). Untreated strips with permanent boards separated each block from another*. These were used during the application of the chemicals and later for collecting information concerning both sand erosion and sand accumulation and any other observations such as the growth of plants under the effect of various treatments and the destruction of the chemically treated surfaces.

At sites 1 and 3 an attempt was made to measure the amount of erosion or deposition occurring. To acheive this, four, 30 cm long canes were driven into each plot at intervals of 0.5 - 1.0 m (the layout for site 1 is shown in figure 8.22). The amount of erosion/deposition that had taken place was recorded at each visit to the site. Owing to the almost total burial of site 3, the only long term data set obtained was from site 1 (see below).

8.4 Effect of Soil Chemical Stabilizers on the Side Erosion of Plots

Measurements of the side erosion of plots and regular photographs for all three sites were taken almost every two weeks. These were as follows:-

i. Site 1:-

Figures (8.6 - 8.11) illustrate the side erosion and breakdown of the plots surface layer for this site. The shaded areas represent sand erosion (ie. the surface lowering as indicated by the erosion sticks). It is clear from the figures (8.6 - 8.8) that, the control plots were the only ones in this site that lost some

* *Vandals later removed these boards, however they did little damage to any of the plots.*

Figure 8.3: Destribution of the Chemical Treatments on the Druridge Bay Field Site 1.

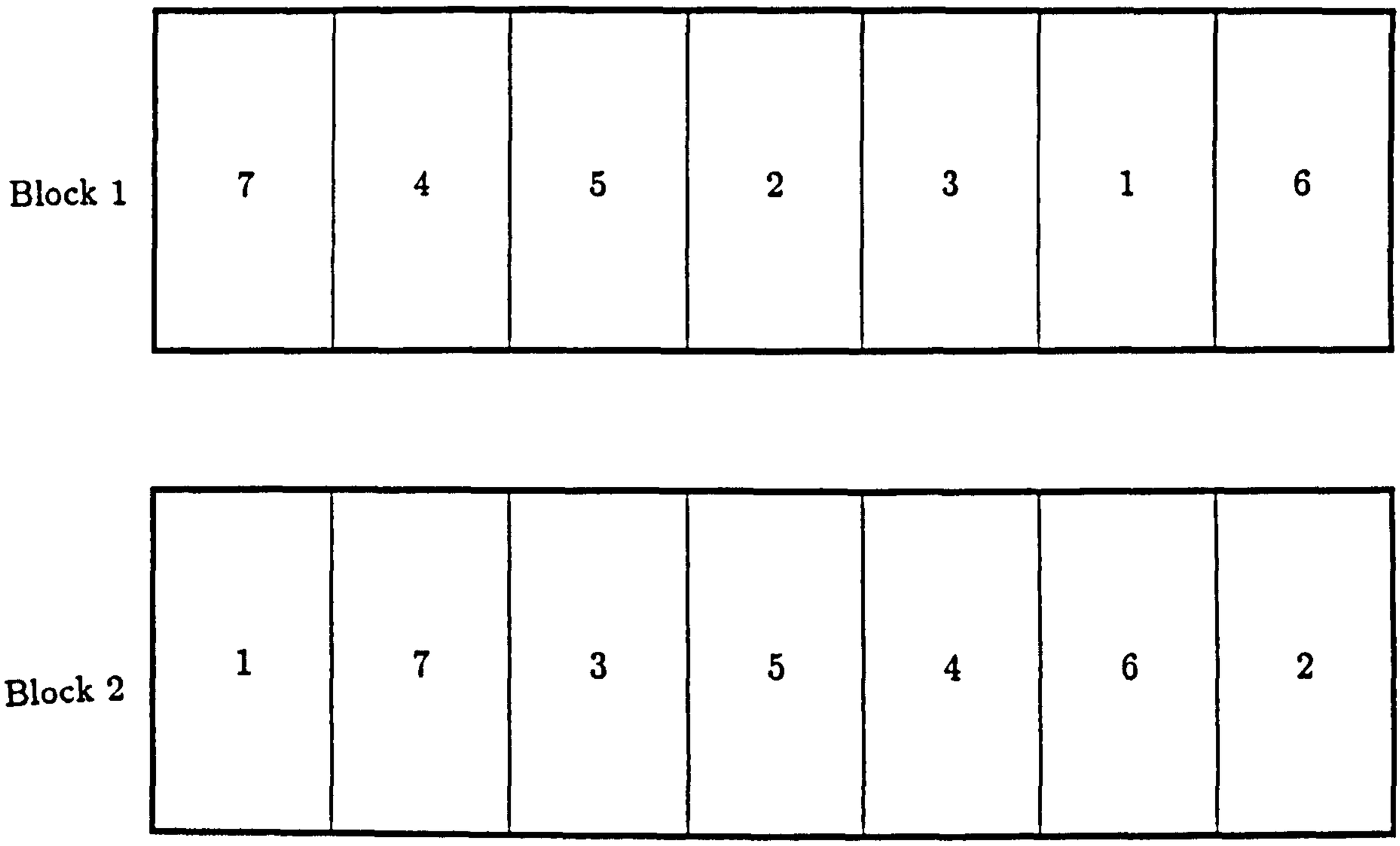
7	3	5	6	2	1	4

1	7	3	2	6	4	5

5	3	2	1	4	6	7

* 1. F.E. 0.2 l m^{-2}; 2. F.E. 0.4 l m^{-2}; 3. B.E. 0.5 l m^{-2}; 4. B.E. 1.0 l m^{-2}; 5. Aq1 0.66%; 6. Aq1 1.0%; 7. Control

Figure 8.4: Destribution of the Chemical Treatments on the Druridge Bay Field Site 2.



* 1. F.E. 0.2 l m^{-2}; 2. F.E. 0.4 l m^{-2}; 3. B.E. 0.5 l m^{-2}; 4. B.E. 1.0 l m^{-2}; 5. Aq1 0.66%; 6. Aq1 1.0%; 7. Control

Figure 8.5: Destribution of the Chemical Treatments on the Druridge Bay Field Site 3.

Block 1	4	5	1	2	6	7	3
Block 2	1	6	4	5	2	3	7
Block 3	5	4	6	3	7	1	2

* 1. F.E. 0.2 l m^{-2}; 2. F.E. 0.4 l m^{-2}; 3. B.E. 0.5 l m^{-2}; 4. B.E. 1.0 l m^{-2}; 5. Aq1 0.66%; 6. Aq1 1.0%; 7. Control

Figure 8.6: Side Erosion and Breakdown of Surface Layer for Druridge Bay Field Site 1.

Date: 5th Jan. 1989

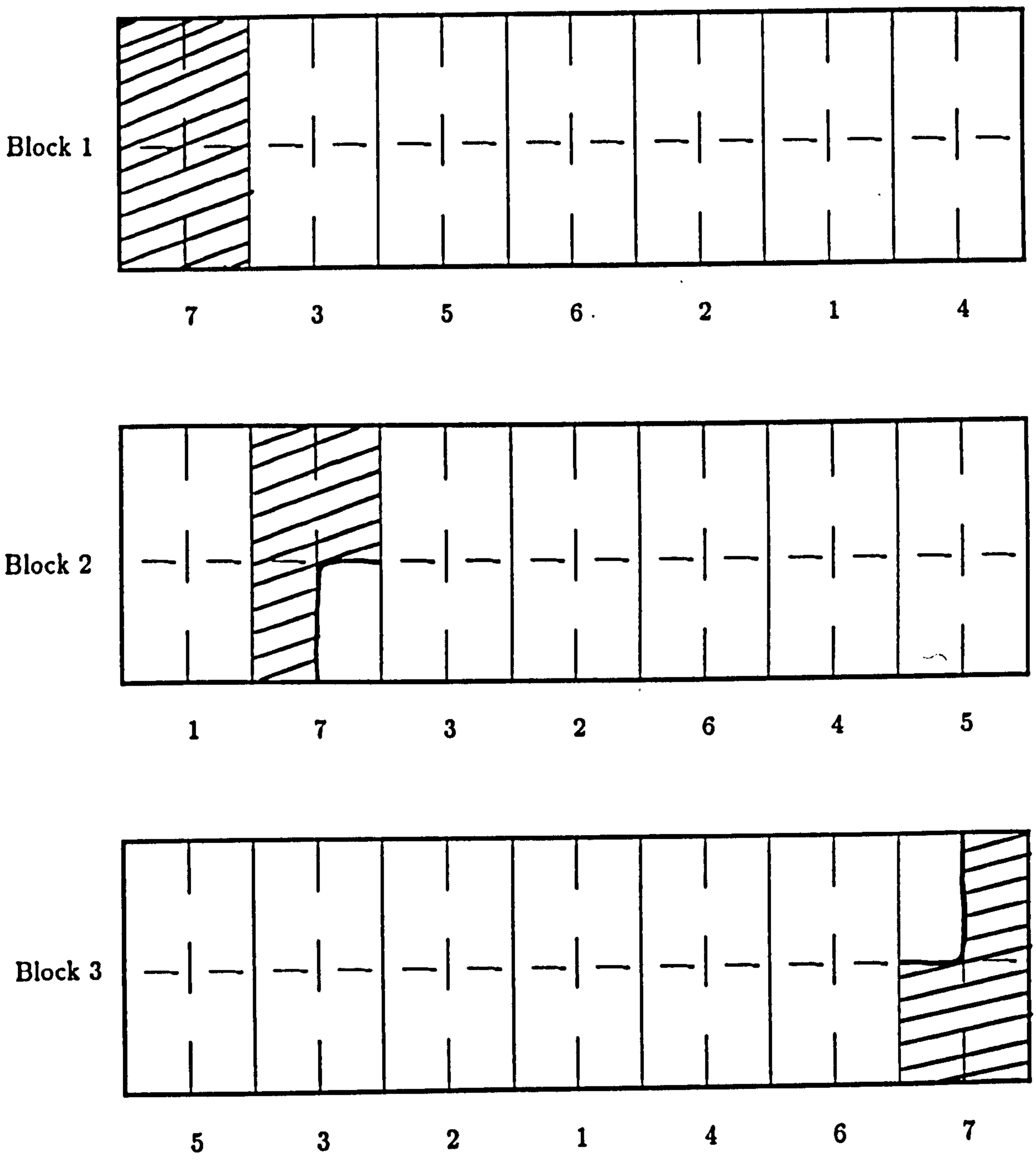


Figure 8.7: Side Erosion and Breakdown of Surface Layer for Druridge Bay Field Site 1.

Date: 18th Jan. 1989

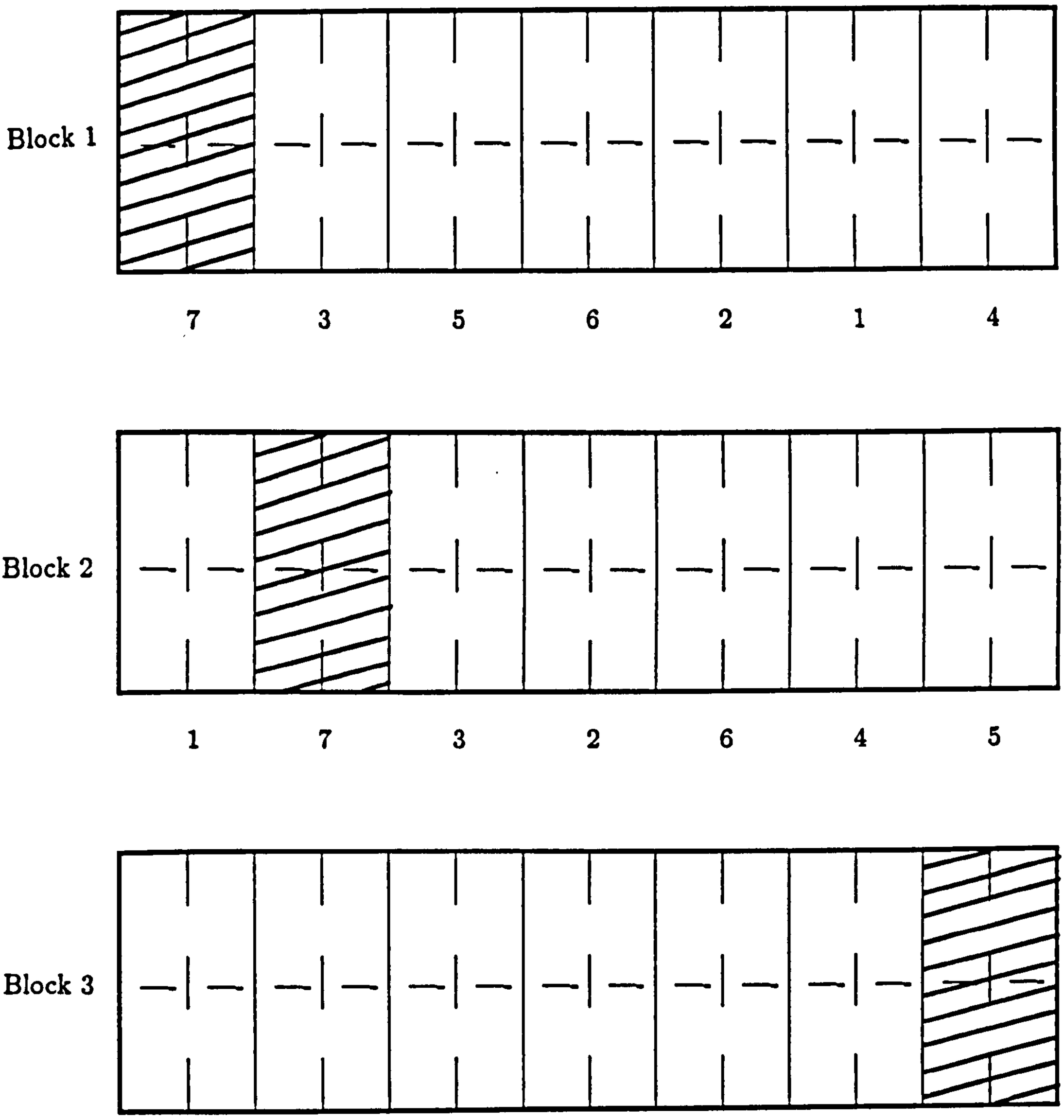


Figure 8.8: Side Erosion and Breakdown of Surface Layer for Druridge Bay Field Site 1.

Date: 25th Jan. 1989

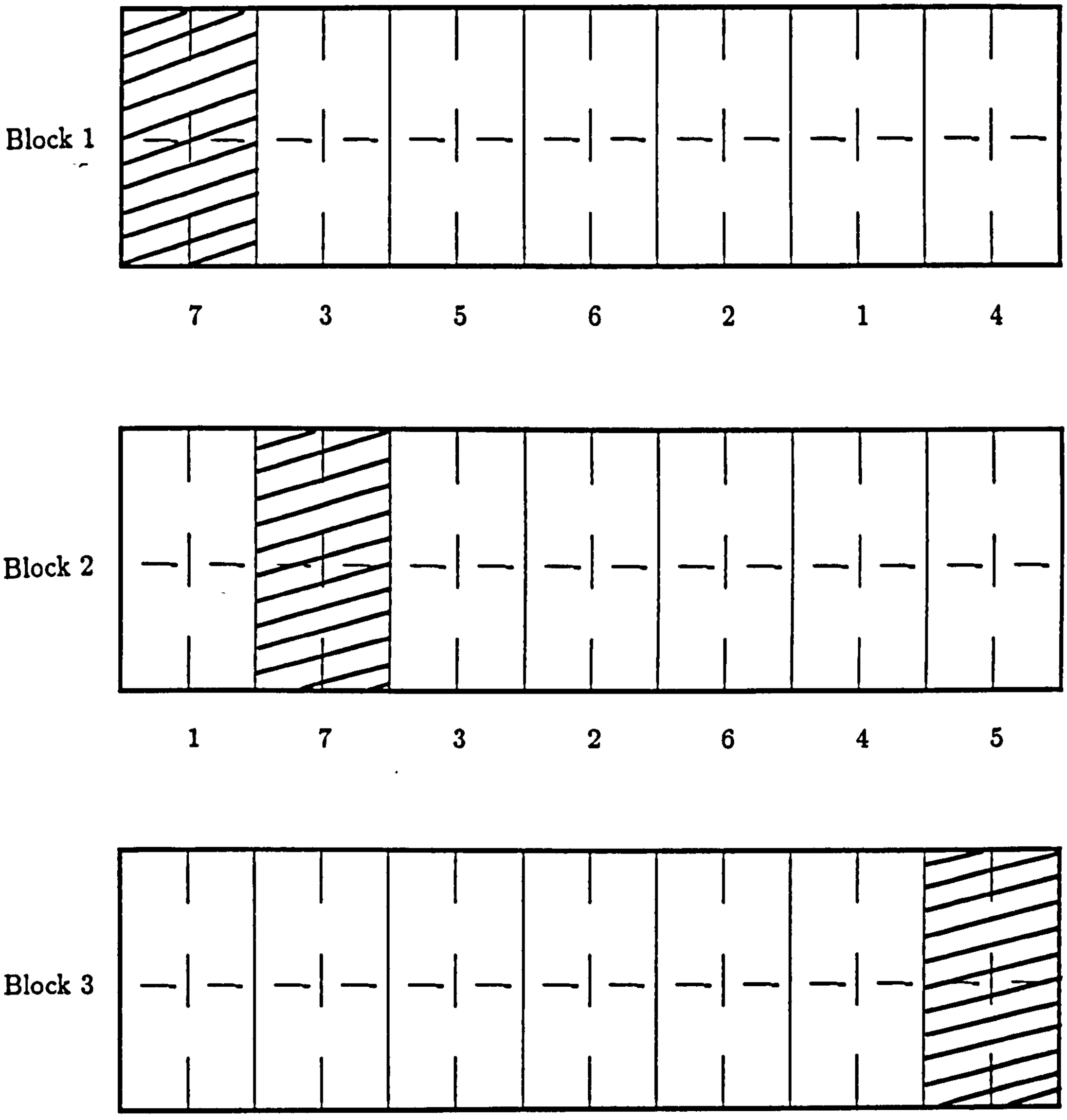


Figure 8.9: Side Erosion and Breakdown of Surface Layer for Druridge Bay Field Site 1.

Date: 20th Sep. 1989

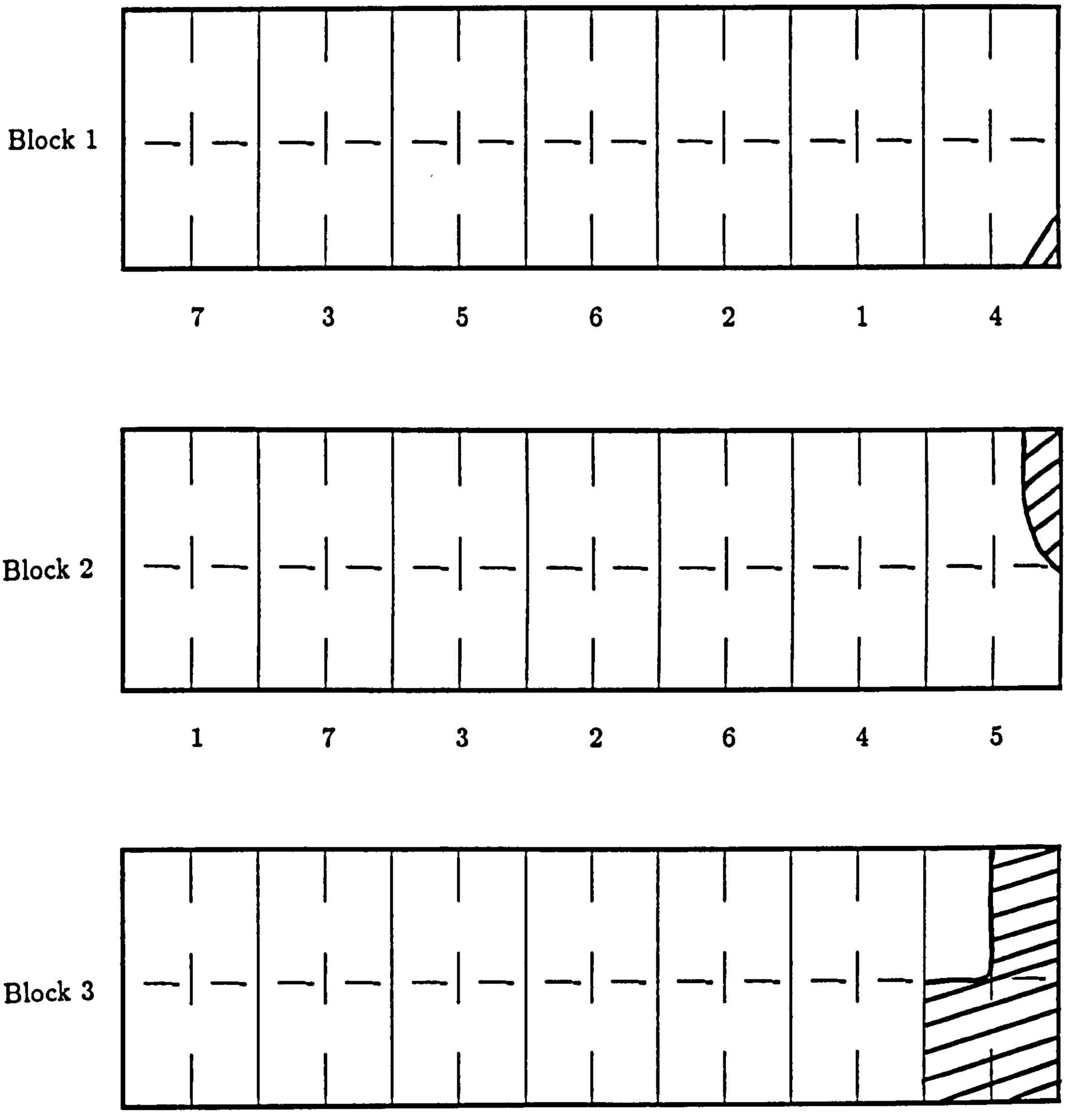


Figure 8.10: Side Erosion and Breakdown of Surface Layer for Druridge Bay Field Site 1.

Date: 15th May 1990

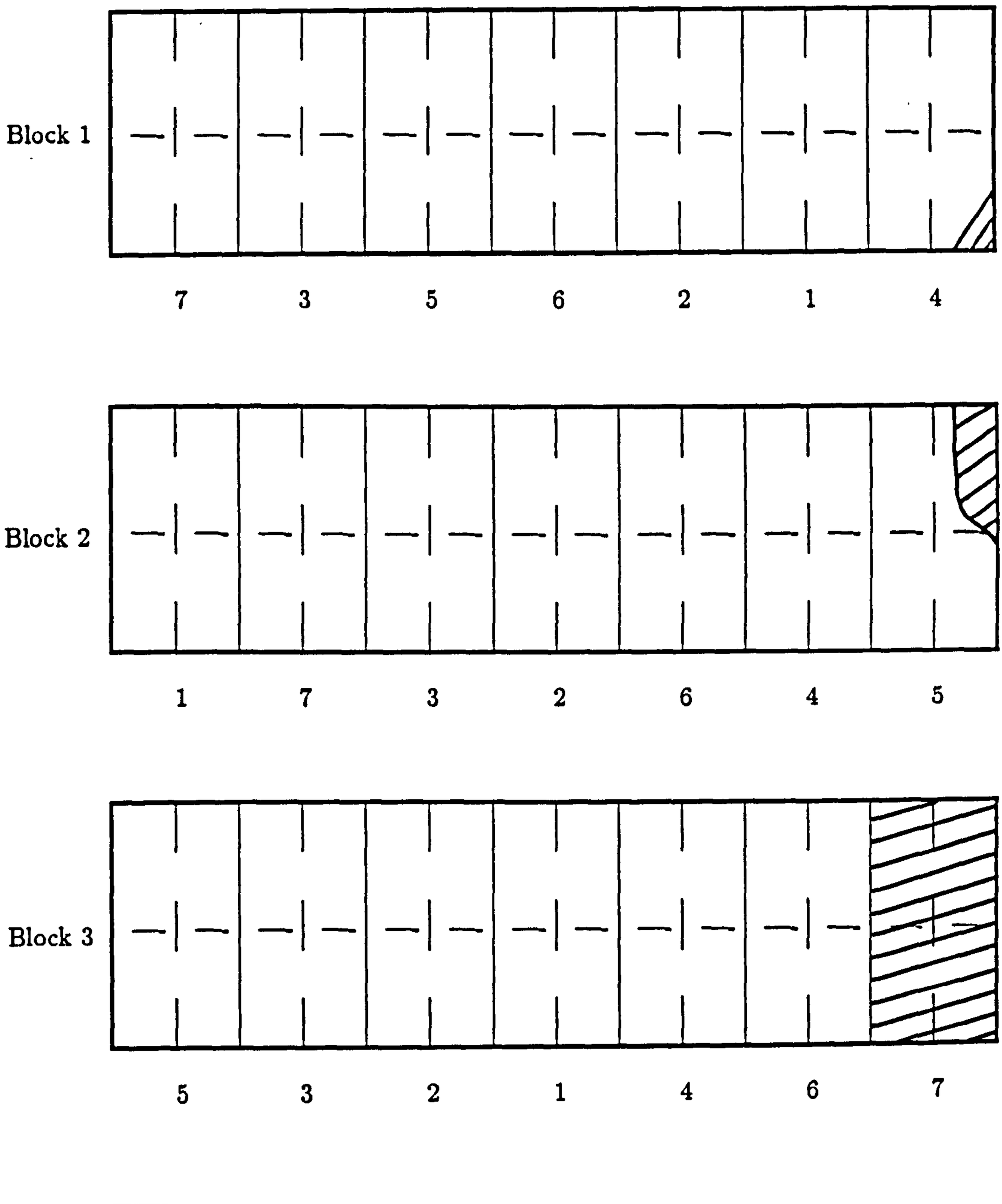
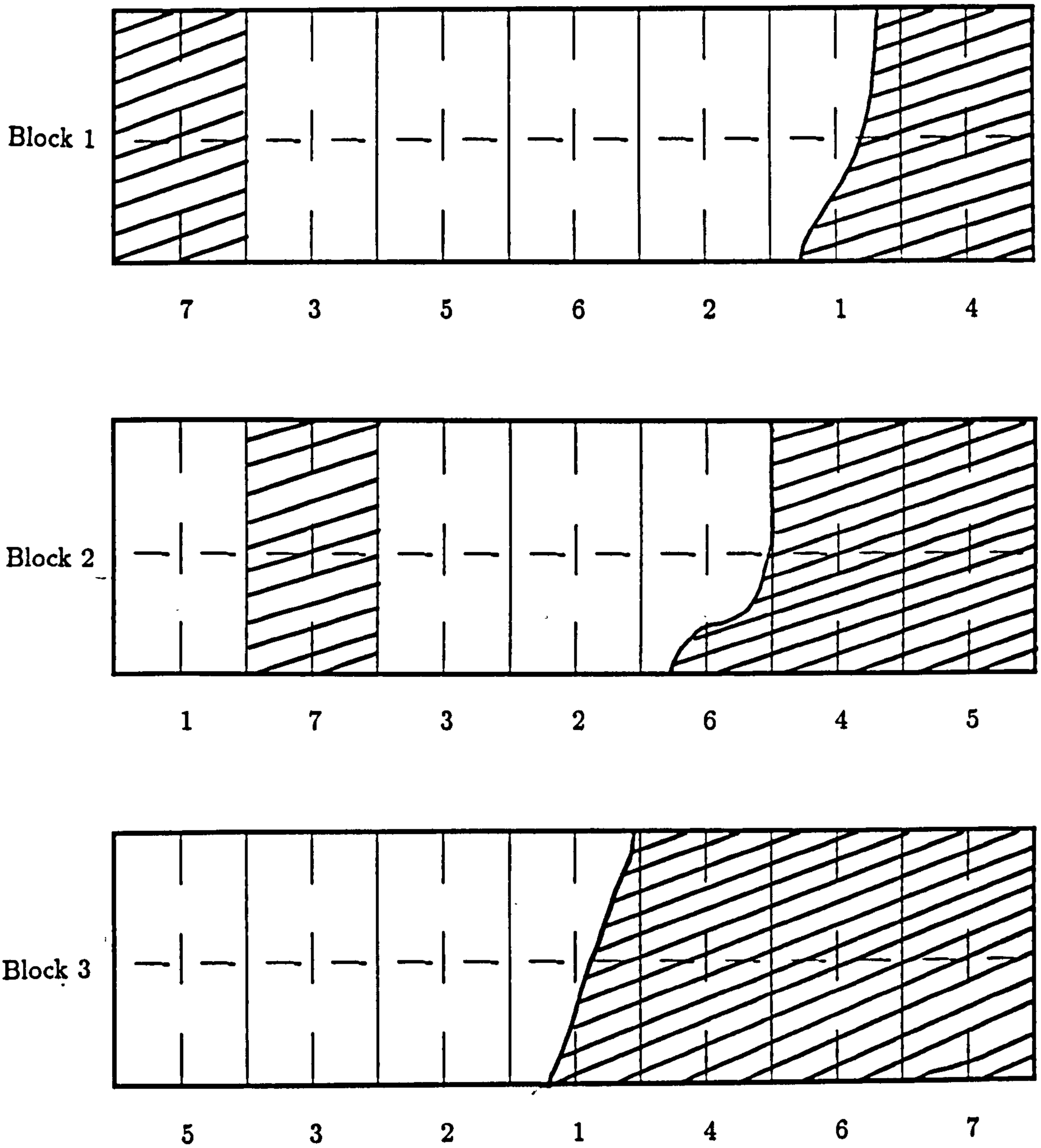


Figure 8.11: Side Erosion and Breakdown of Surface Layer for Druridge Bay Field Site 1.

Date: 22nd Sep. 1990



of their sand by 25th January 1989. All the other treatments stayed completely stable against both wind and water erosion. It is important to mention that, the cultivated marram grass tillers were responsible for the accumulation of a large amount of sand on this site (about 43 - 55 cm deep). This was observed on the 7th of February 1989 following two strong windspeed events on 27th and 29th January 1989 with windspeeds of 15 and 12 m sec^{-1} respectively. These caused considerable erosion of adjacent unplanted areas and were the source of the sand accumulating on this site. The role of the surface stabilizers was however stopped due to the above mentioned massive accumulation of sand on the site by 27th and 29th January 1989. Although some erosion occurred during the next 8 months, no further side erosion and breakdown of the surface layer occurred as the above mentioned massive accumulation of sand was never removed in sufficient quantities to expose the chemically stabilized surfaces. Between the 24th August and the 22nd September 1990 however a major sand avalanche* happened to the eastern most plots causing great damage to the site (figure 8.11). Photos (8.12 - 8.18) show the progress in this site as a function of time during 21 months since the spraying of the chemical stabilizers.

ii. Site 2:-

Figures (8.12 - 8.18) illustrate the side erosion and breakdown of the surface layer for this site. The shaded areas represent sand erosion. The increases of the side erosion in this site as a function of time was due to the following reasons:-

1. A sand avalanche occurred on the sea facing side of the sand hill where the site was situated. This occurred on the 19th of December 1988 due to the effect of both wind erosion (14 m sec^{-1}) and sea water erosion caused by the rough sea and high tides on at that date.

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* *Sand Avalanche: Movement of large masses of sand down a dune face when the angle of repose is exceeded, or when the dune is disturbed (Stone, 1967).*

Plate 8.12: Site 1 (25th Jan. 1989).

Plate 8.13: Site 1 (20th June 1989).

Plate 8.14: Site 1 (20th Sep. 1989).

Plate 8.15: Site 1 (15th May 1990).

Plate 8.16: Site 1 (22nd Sep. 1990).

Plate 8.17: The Destruction of the Flexible Aq1 1.0% Layer Due to the Sand Avalanche Occurred in Site 1 (22nd Sep. 1990).

Plate 8.18: The Distribution of the Marram Grass Root System in Site 1 (22nd Sep. 1990).

2. The loss of sand at the down slope edge as a result of down-slope creep of loose sand from beneath the treated surface. Photo (8.19) indicates the destruction of the flexible Aq1 0.66% layer due to the sand creeping from below the treated surface.

3. The thinner lyme grass plant cover in this site compared with the marram grass cover at both sites 1 and 3.

4. The frequent high windspeeds, for example:-

i. A windspeed of 10 m sec^{-1} on both 11th and 13th January 1989 was responsible for the increase of the side erosion on this site indicated in figure (8.14) comparing with the figure (8.13).

ii. Windspeeds of 15 and 12 m sec^{-1} respectively in 27th and 29th January and the 10 m sec^{-1} in the 5th February 1989 were responsible for the destruction of block 3 and more breakdown in both blocks 1 and 2 (figures 8.15 and 8.16).

Figure 8.12: Side Erosion and Breakdown of Surface Layer for Druridge Bay Field Site 2.

Date: 20 Dec. 1988

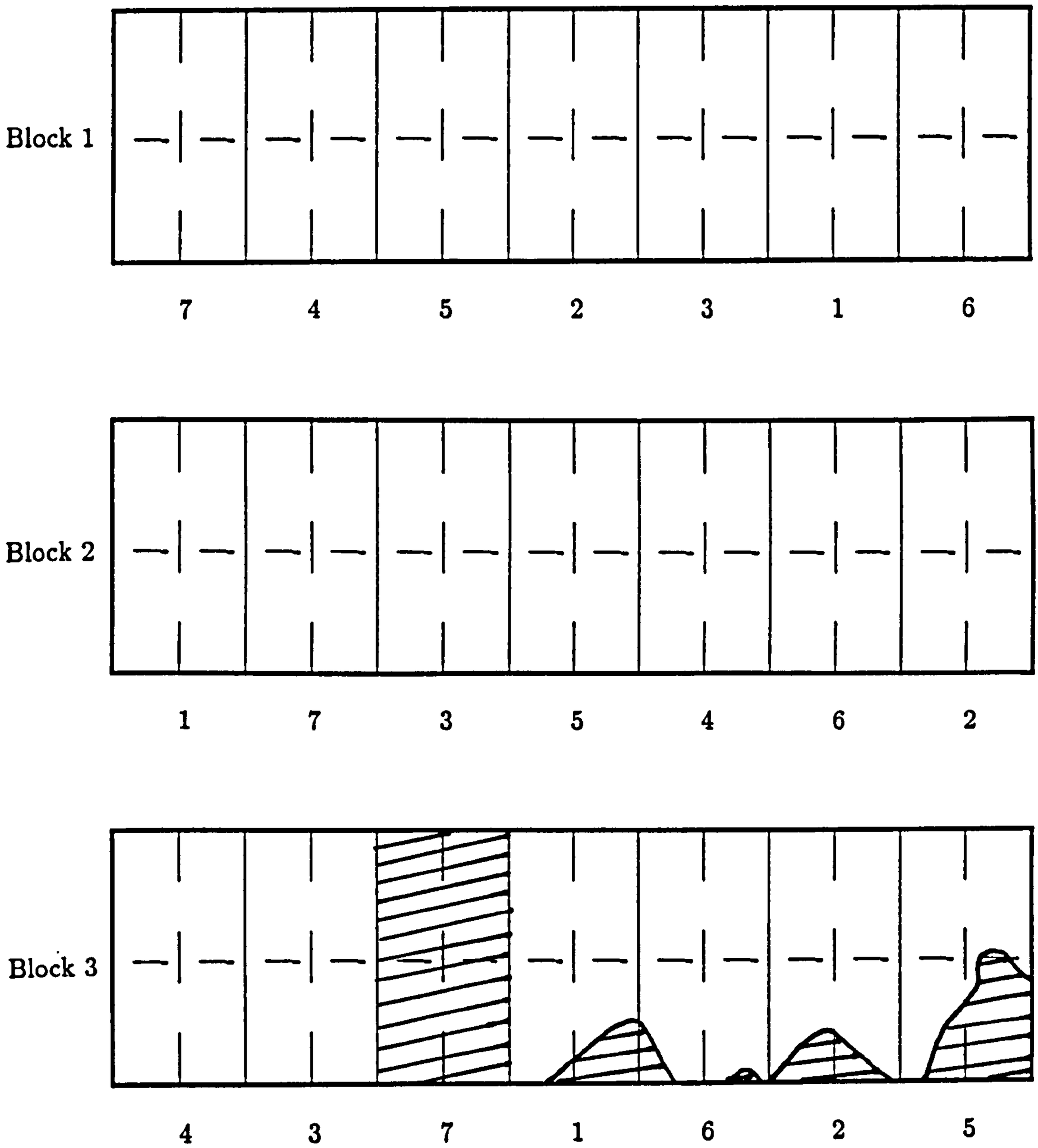


Figure 8.13: Side Erosion and Breakdown of Surface Layer for Druridge Bay Field Site 2.

Date: 5th Jan. 1989

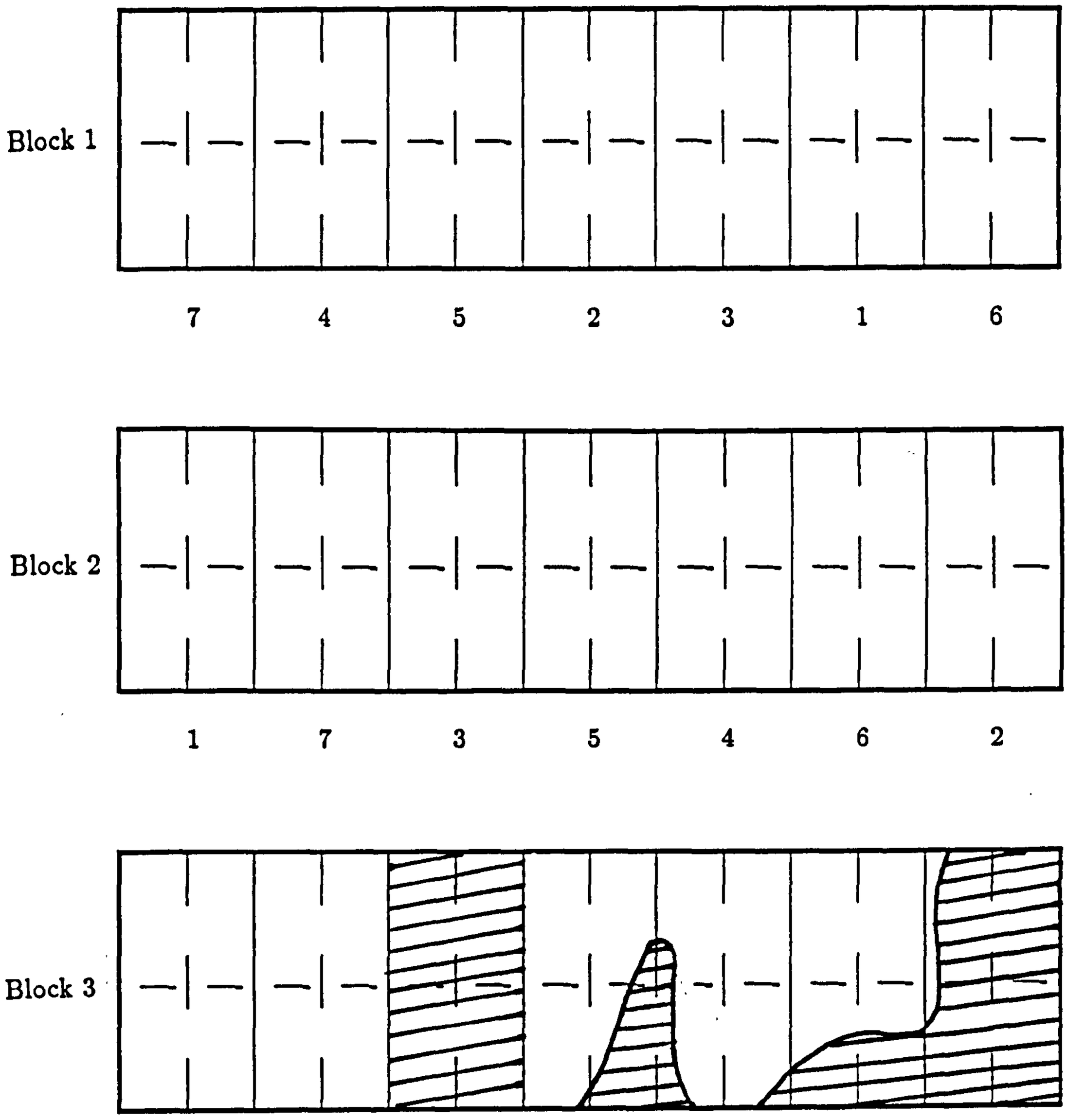


Figure 8.14: Side Erosion and Breakdown of Surface Layer for Druridge Bay Field Site 2.

Date: 18 Jan. 1989

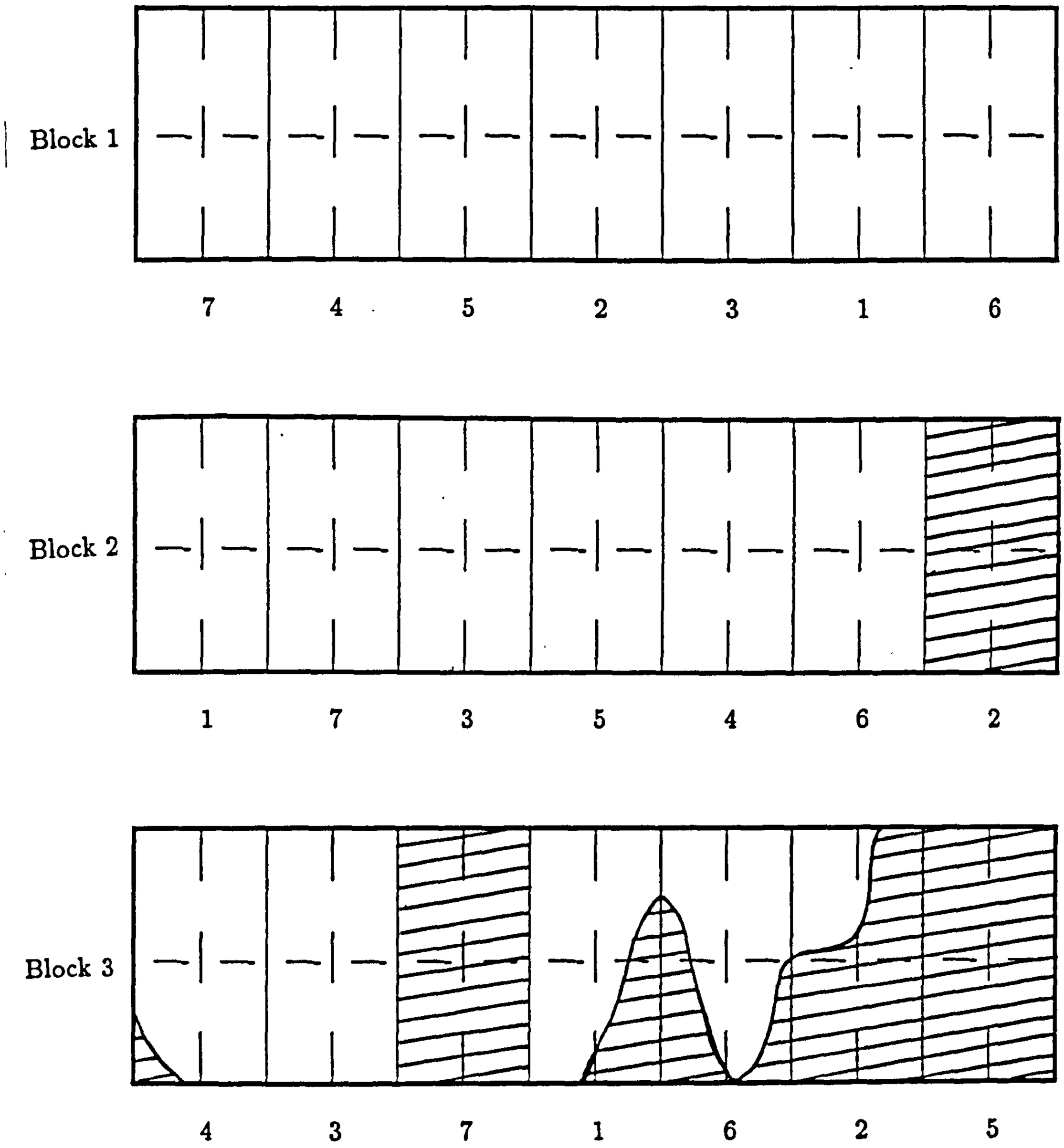


Figure 8.15: Side Erosion and Breakdown of Surface Layer for Druridge Bay Field Site 2.

Date: 25 Jan. 1989

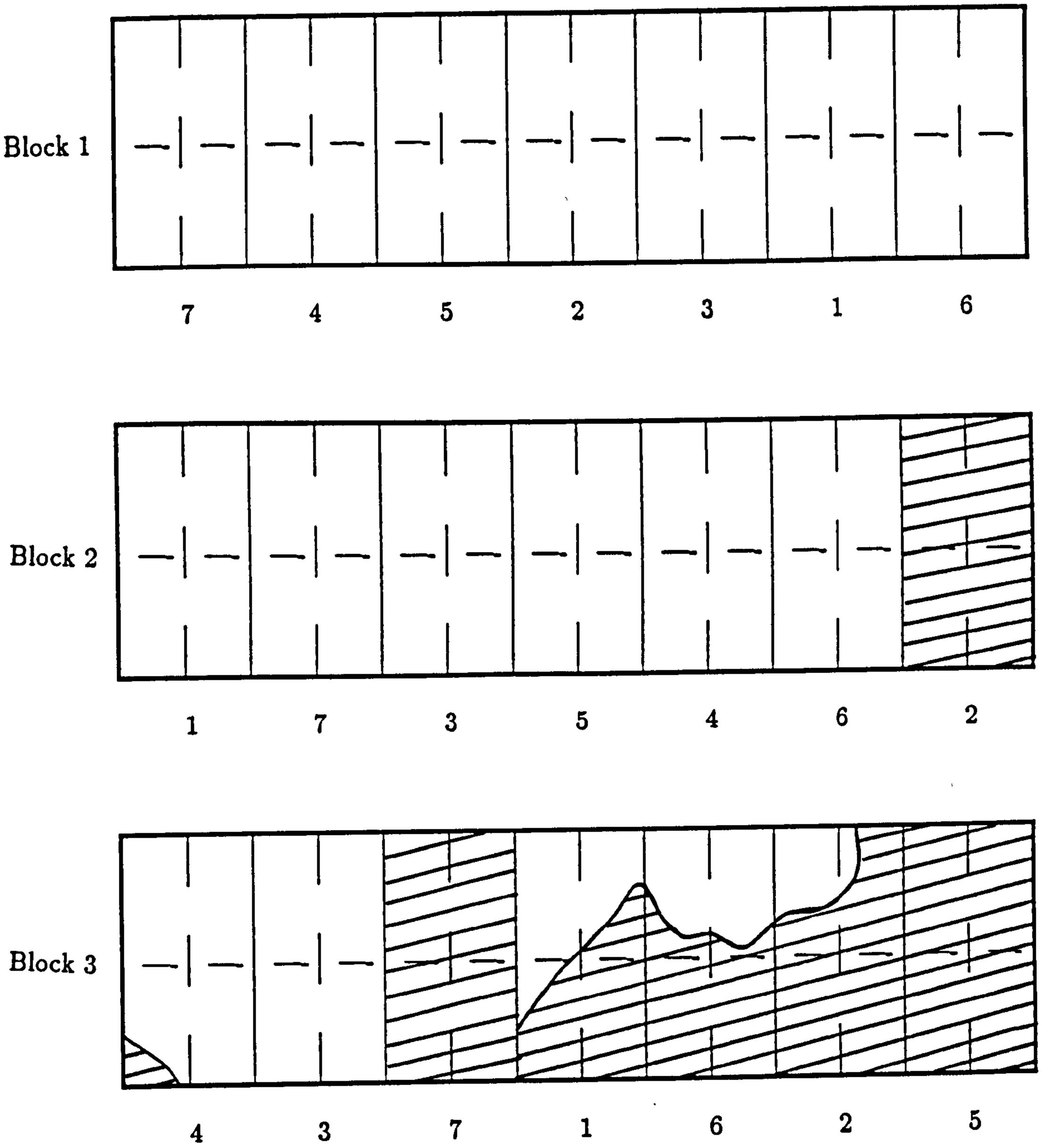


Figure 8.16: Side Erosion and Breakdown of Surface Layer for Druridge Bay Field Site 2.

Date: 7th Feb. 1989

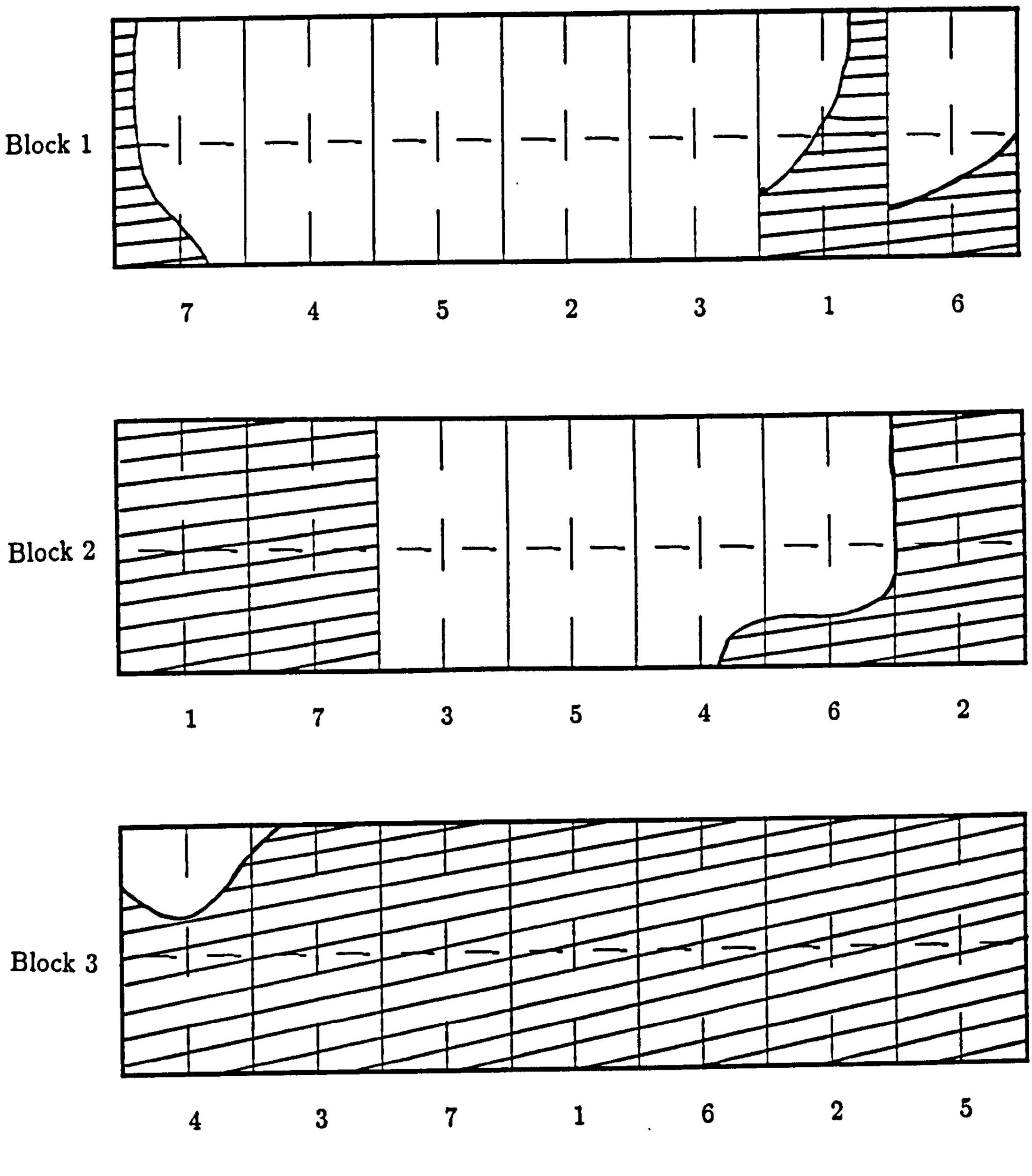


Figure 8.17: Side Erosion and Breakdown of Surface Layer for Druridge Bay Field Site 2.

Date: 24 Feb. 1989

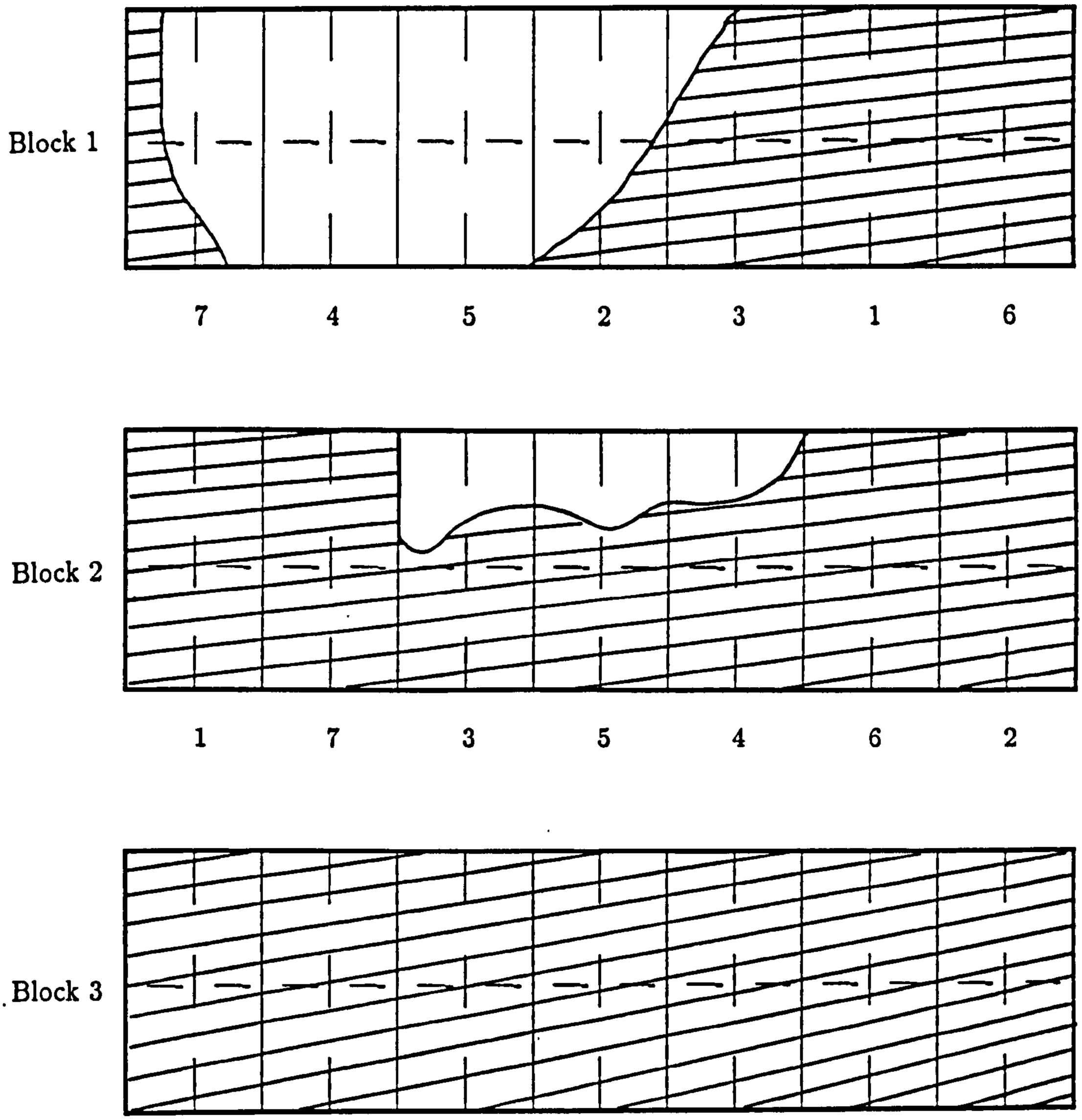


Figure 8.18: Side Erosion and Breakdown of Surface Layer for Druridge Bay Field Site 2. Date: 7th Mar. 1989

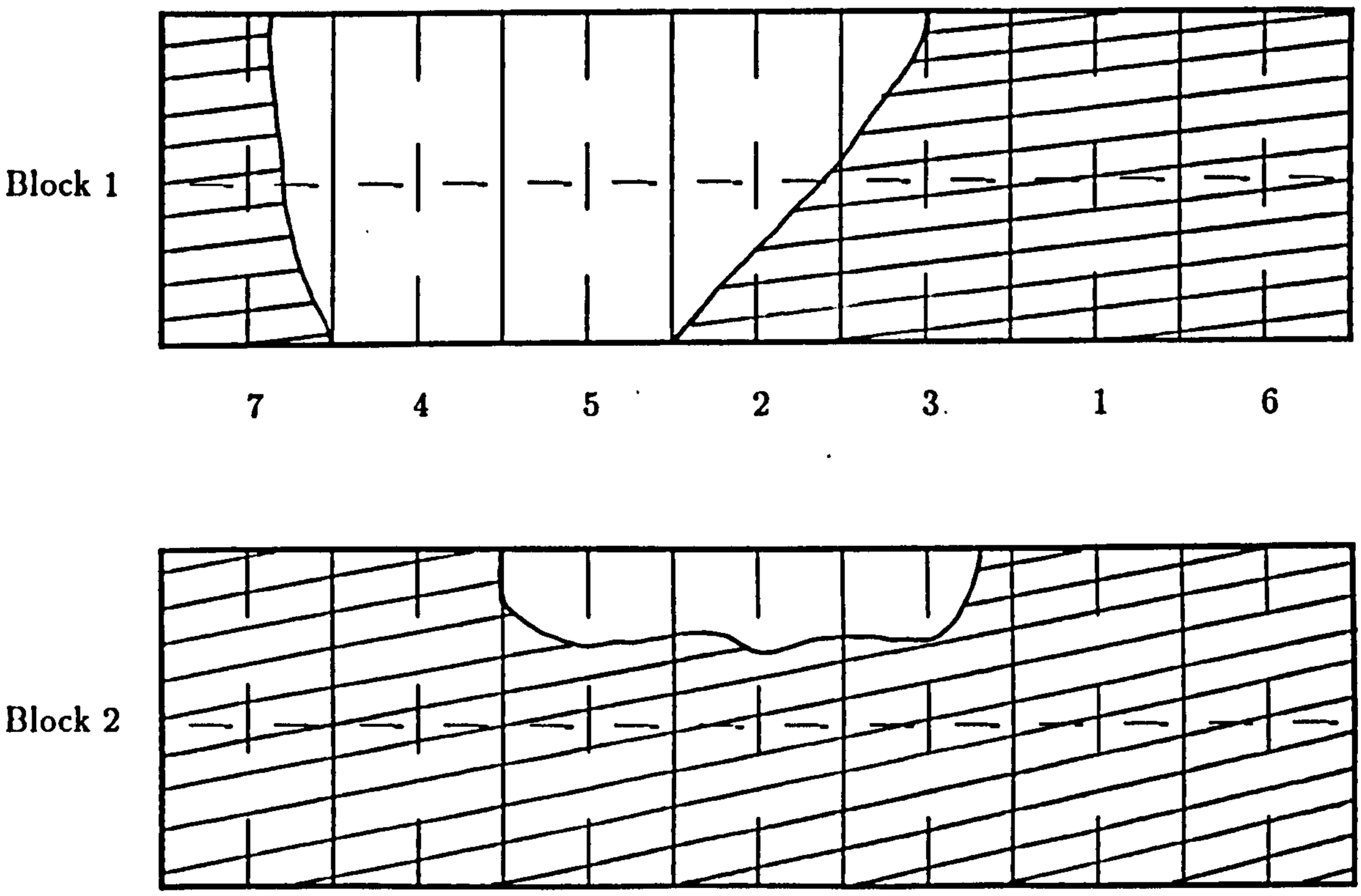


Plate 8.19: The Destruction of the Flexible Aq1 0.66% Layer Due to Downslope Sand Creep from the Underlying Untreated Layer (7th Feb. 1989).

iii. Most damage however occurred at site 2 during February and the begining of March 1989 as the windspeed increased to 10 m sec^{-1} (4 times); 12 m sec^{-1} (one time) and 14 m sec^{-1} (twice). Figures 8.17 and 8.18 illustrate the almost complete destruction of this site only 4 months after being treated with the chemical stabilizers. Therefore, no more side erosion and breakdown of the surface layer diagrams were drawn for this site after the 7th March 1989.

5. Despite the total loss of this site by March - it is significant that within only 4 weeks of establishment the control plot in block 3 was eroded.

Photos (8.20 - 8.30) illustrate the progress in site 2 as a function of time during one year and 3 months starting from 20th November 1988.

Plate 8.20: Site 2 (20th Dec. 1988).

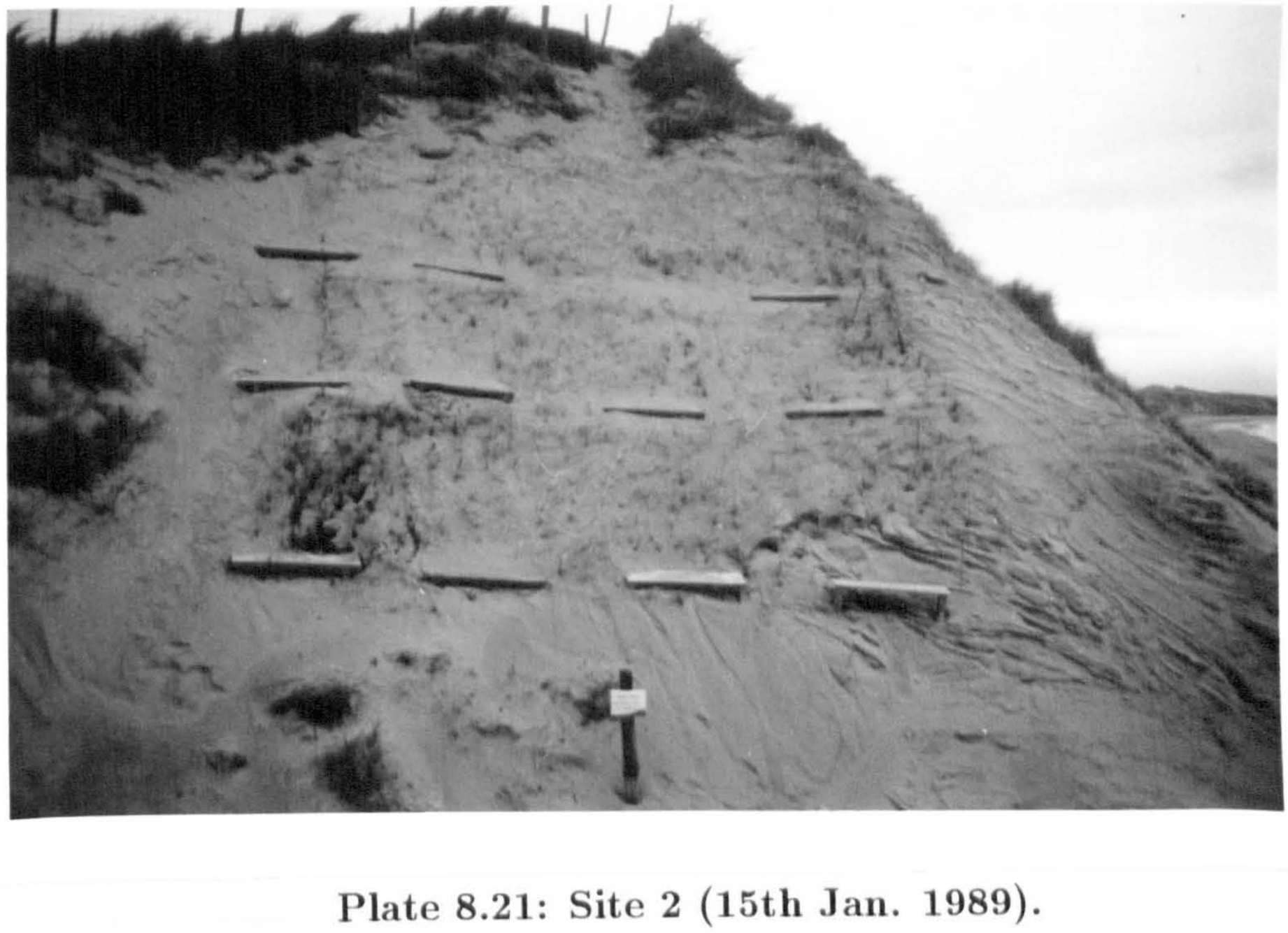


Plate 8.21: Site 2 (15th Jan. 1989).

Plate 8.22: Site 2 (25th Jan. 1989).

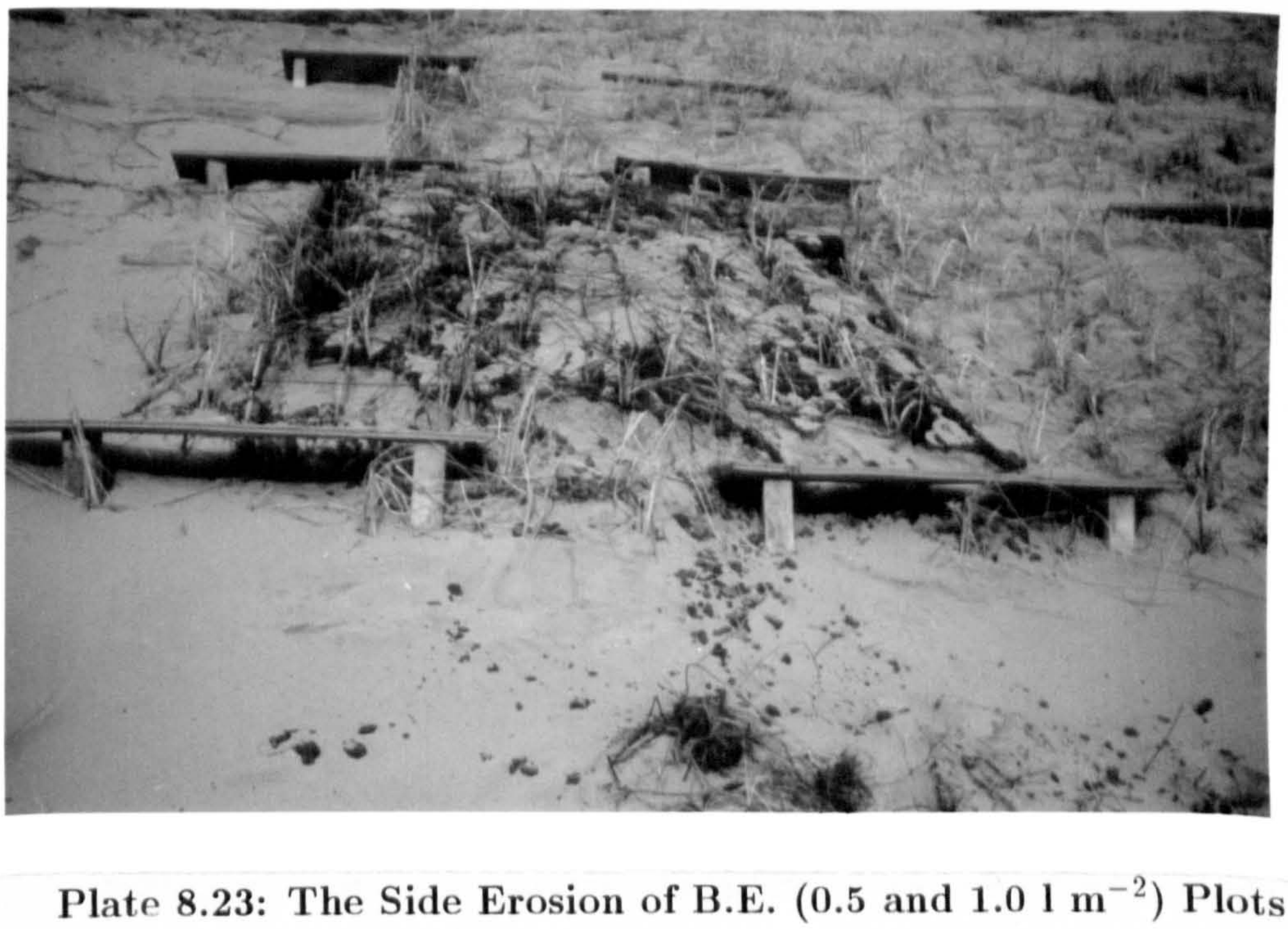


Plate 8.23: The Side Erosion of B.E. (0.5 and 1.0 l m^{-2}) Plots in Block 3 Site 2 (25th Jan. 1989).

Plate 8.24: Site 2 (7th Feb. 1989).

Plate 8.25: The Destruction of the Flexible Aq1 1.0% Layer Due to the Sand Avalanche Occurred in Site 2 (7th Feb. 1989).

Plate 8.26: The Downslope B.E. (1.0 l m^{-2}) Layer Due to the Sand Avalanche Occurred in Site 2 (7th Feb. 1989).

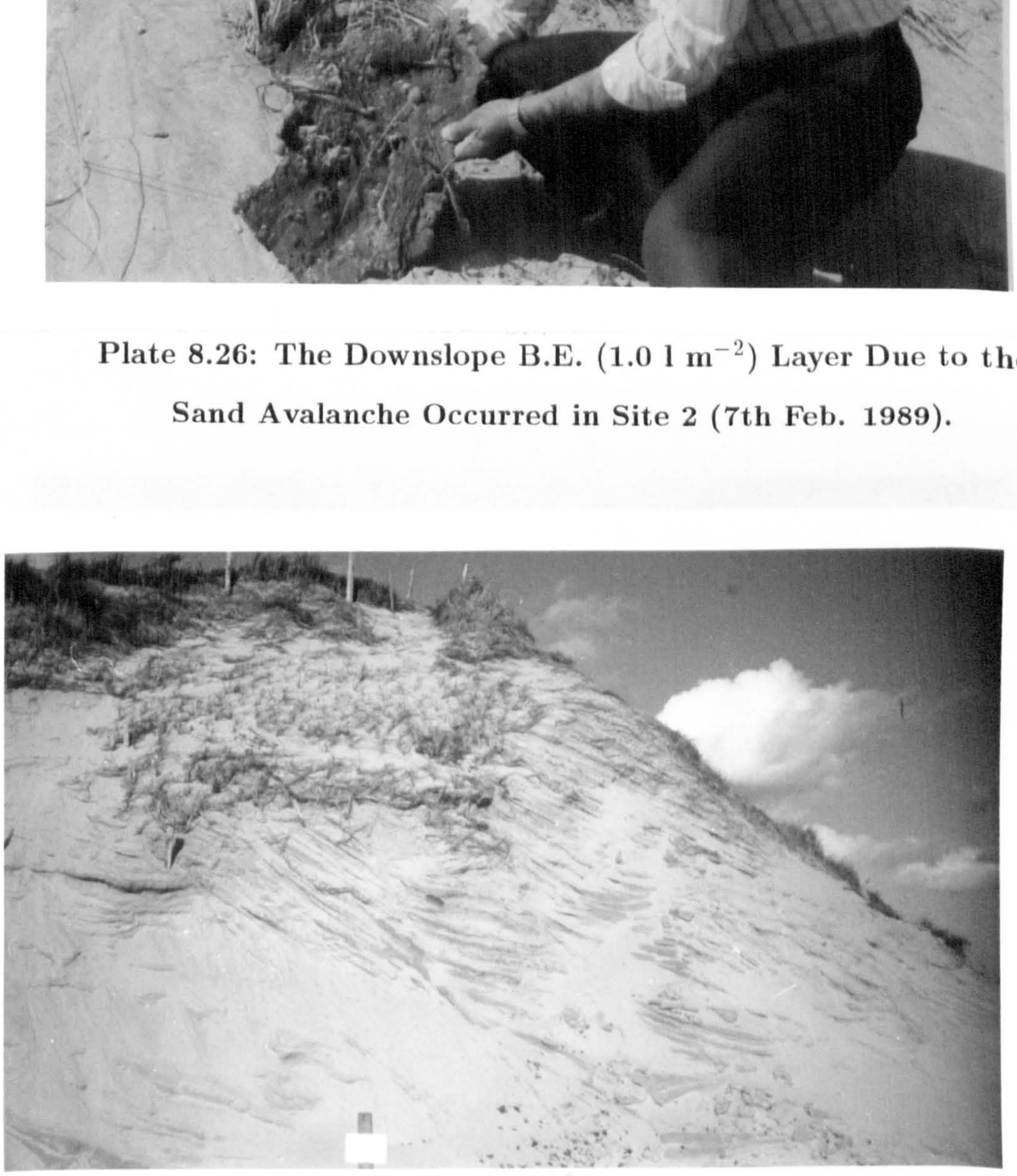


Plate 8.27: Site 2 (7th Mar. 1989).

Plate 8.28: Site 2 (20th Apr. 1989).

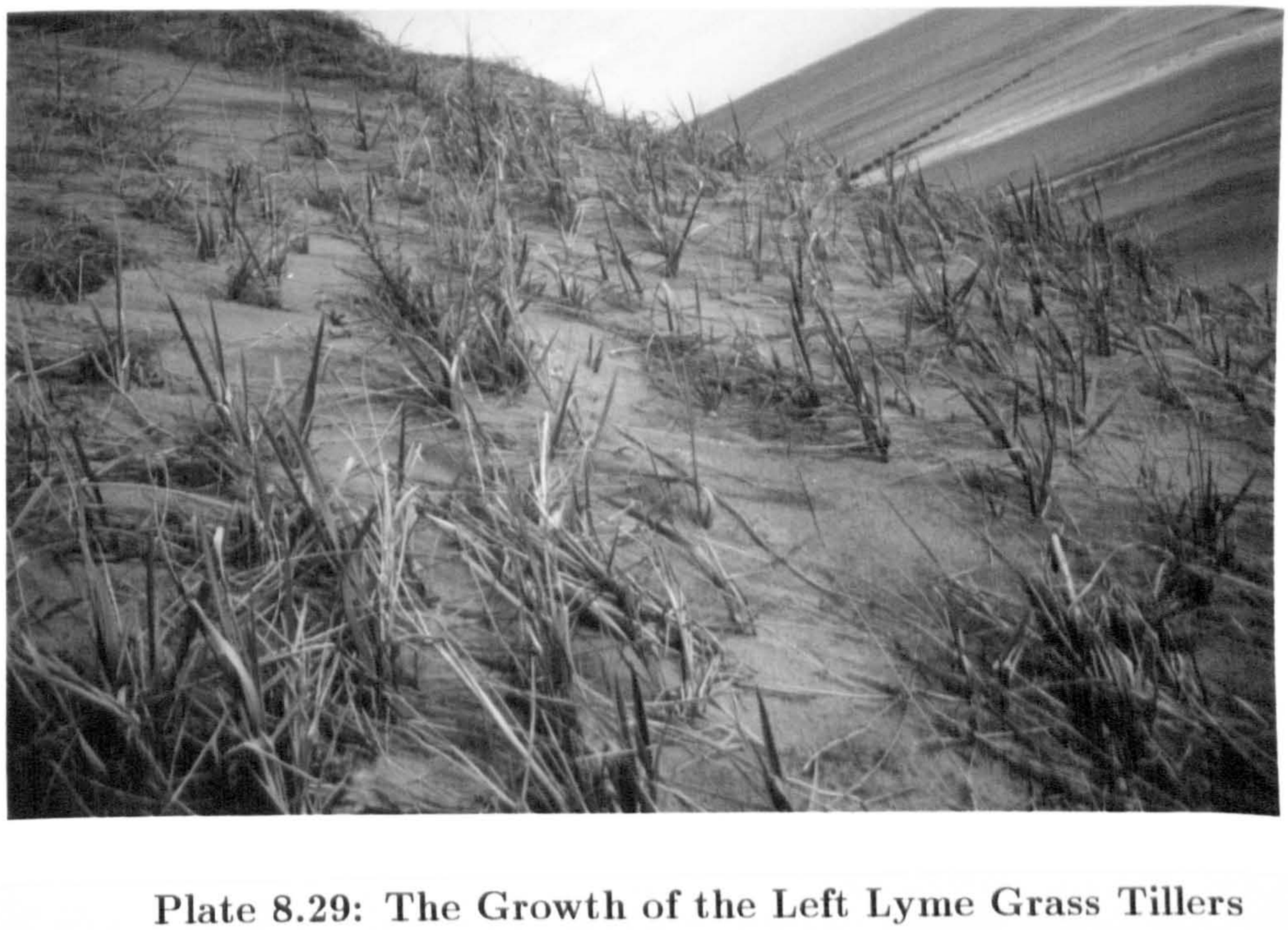


Plate 8.29: The Growth of the Left Lyme Grass Tillers in Site 2 (20th Apr. 1989).

Plate 8.30: The Downslope Flexible Aq1 Layer Due to the Sand Avalanche Occurred in Site 2 (22nd Feb. 1990).

iii. Site 3:-

Figures (8.19 - 8.21) illustrate the side erosion and breakdown of the surface layer for site 3. The shaded areas indicate the sand side erosion from the plots. It is clear from all the figures (8.19 - 8.21) that the control plots followed by F.E. 0.2 l m^{-2}in block 3 were the only ones in this site that lost some of their sand. All the other treatments stayed completely stable against both wind and water erosion. Furthermore, the planted marram grass tillers trapped a large amount of sand on this site especially on blocks 2 and 3 (about 30 - 60 cm deep). This was again due to the two strong windspeed events on the 27th and 29th of January 1989 with windspeeds of 15 and 12 m sec^{-1}) respectively. The large amount of sand on both blocks 2 and 3 was responsible for the death of some marram grass plants. Photos (8.31 and 8.32) indicate the accumulation of the large amount of sand, and consequently the reduction in the number of the marram grass tillers in

Figure 8.19: Side Erosion and Breakdown of Surface Layer for Druridge Bay Field Site 3.

Date: 20 Dec. 1988

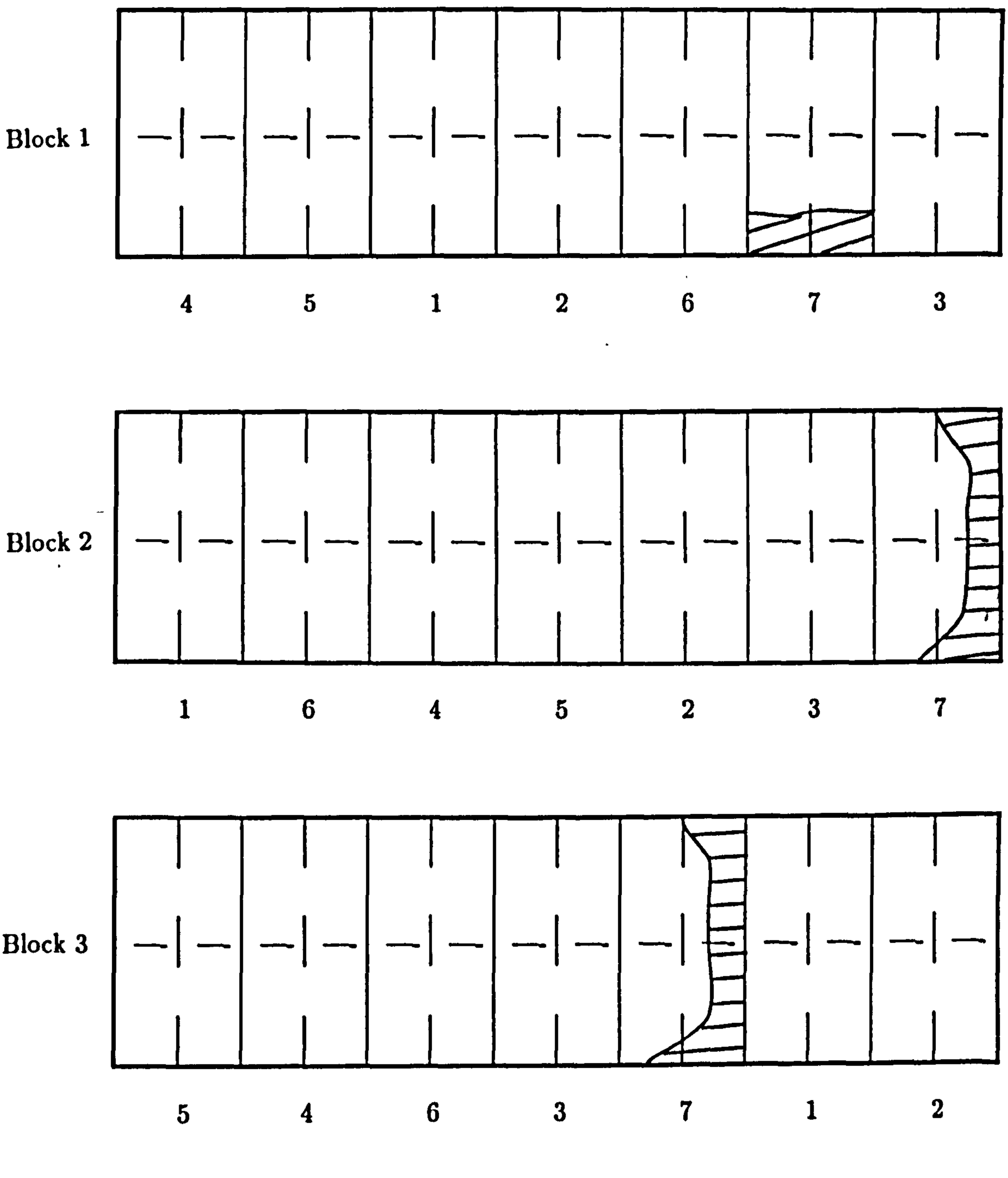


Figure 8.20: Side Erosion and Breakdown of Surface Layer for Druridge Bay Field Site 3.

Date: 5th Jan. 1989

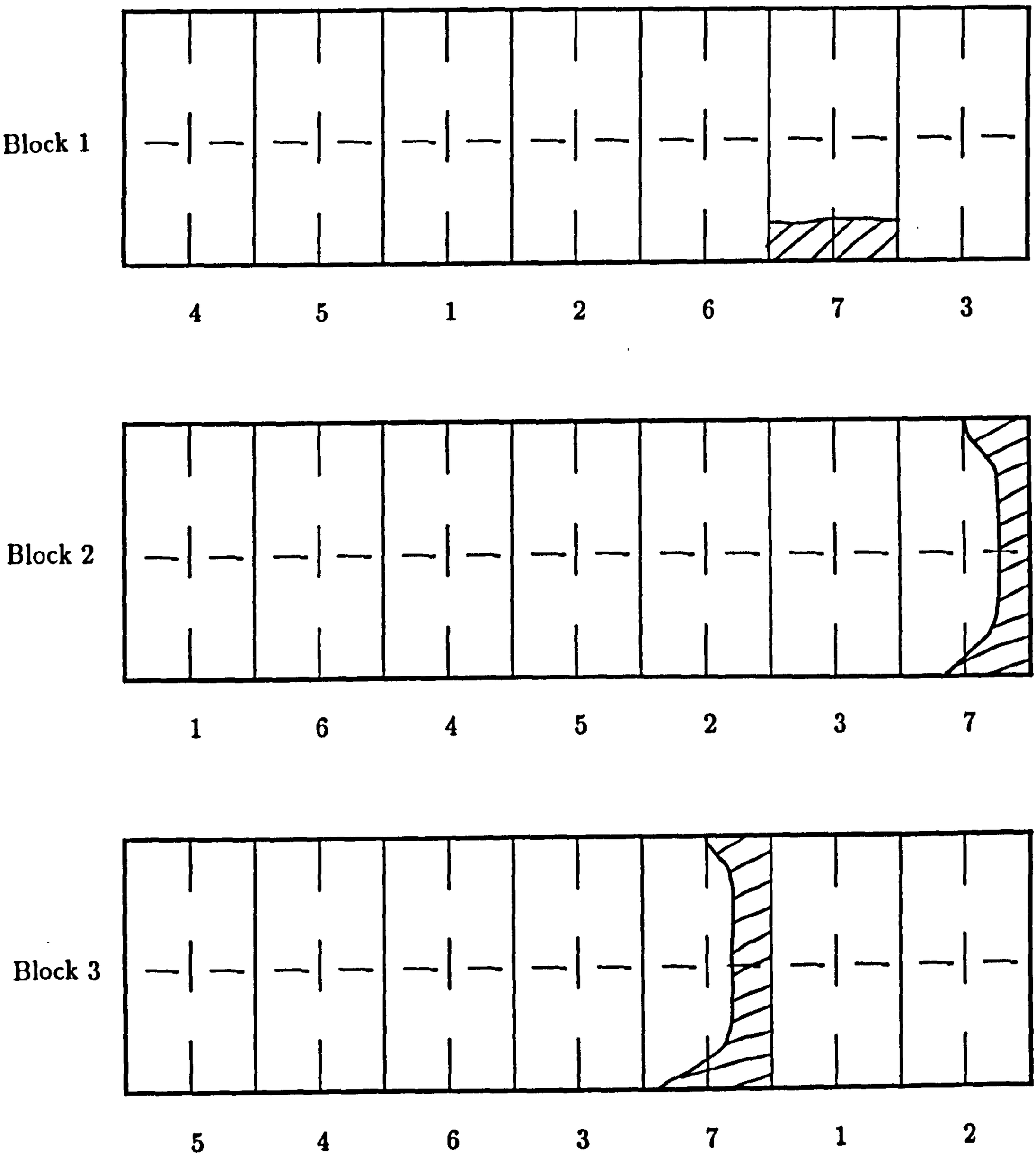


Figure 8.21: Side Erosion and Breakdown of Surface Layer for Druridge Bay Field Site 3.

Date: 18 Jan. 1989

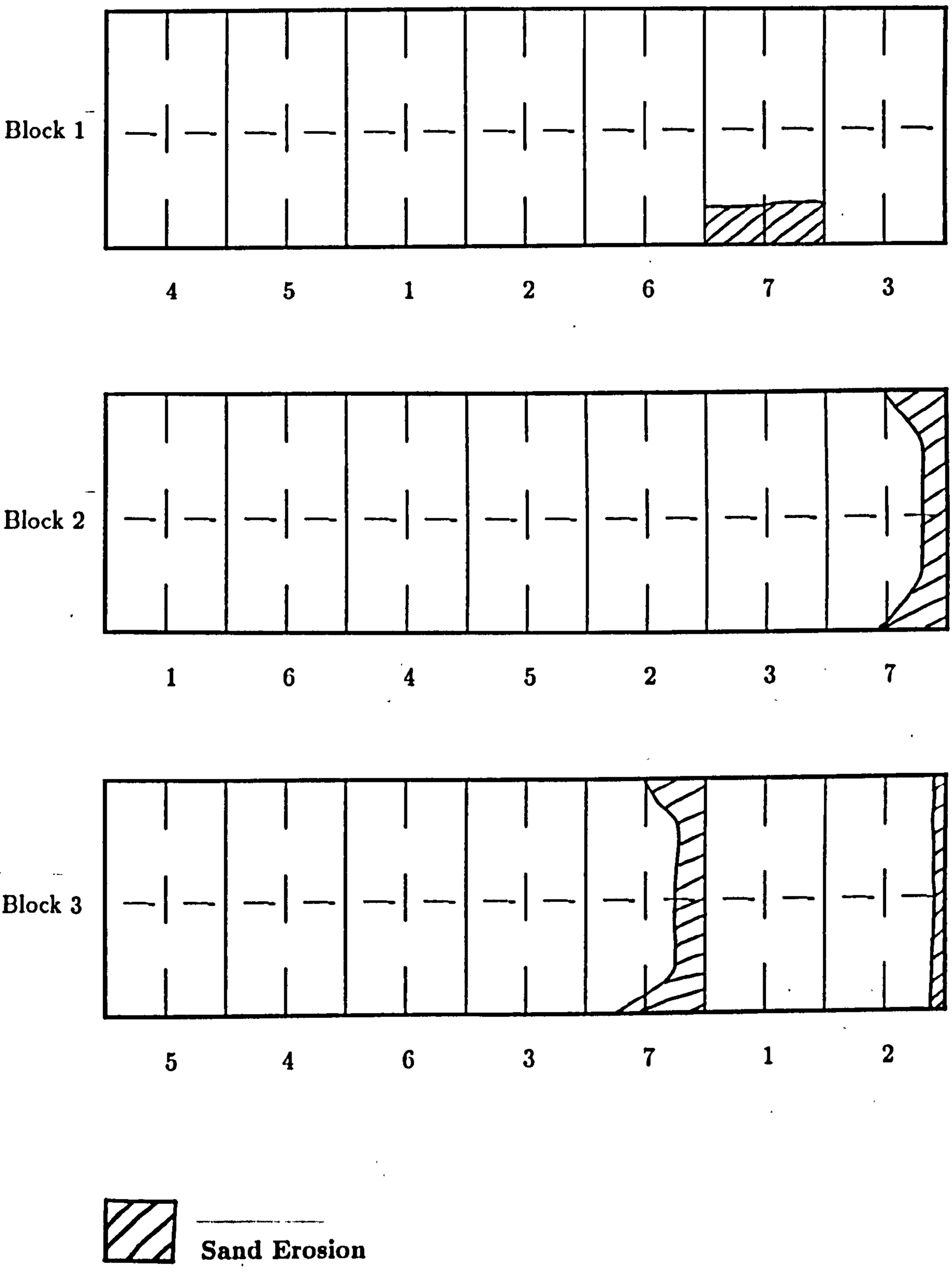


Plate 8.31: Massive Sand Accumulation on Both Blocks 2 and 3 Site 3 (7th Feb. 1989).

Plate 8.32: High Reductions in Marram Grass Tillers in Both Blocks 2 and 3 Site 3 (7th Mar. 1989).

both blocks 2 and 3. Whilst, photo 8.33 shows the growth of some new marram grass tillers after being buried for about 4 months under the sand.

Plate 8.33: The Growth of Some New Marram Grass Tillers in Site 3 After Being Buried for About 4 Months Under the Sand (22nd May 1989).

8.5 Effect of Soil Chemical Stabilizers on the Plots Sand Erosion and Sand Accumulation

Rates of sand loss and sand deposition depend upon the size and shape of a dune, sand supply, foredune condition, state of the vegetation cover, sand particle size and the velocity and direction of the airflow (Holland, 1983; and Watson, 1987).

Although 'erosion sticks' were installed at sites 1 and 3, site 3 was almost totally inundated with sand by the events of 27th and 29th of January 1989, and thus was also ruled out as a long term source of information on erosion and deposition. Thus only site 1 was able to furnish any long term information. The

changes in sticks 'heights' depending on their marked midpoint were measured regularly during nine months starting from the 20th December 1988 (appendix tables 8.1 - 8.8). The sticks were fixed in the sand at their zero point (midpoint) after every measurement. Sand erosion (E) and sand accumulation (A) (tables 8.3 - 8.10) are the mean depths of four readings of the surface materials lost or gained as measured on the sticks within the period of time between the previous reading and the new one. The position of the 'sticks' is shown in figure 8.22.

From the results in tables (8.3 - 8.10) and appendix tables (8.1 - 8.8), the following points can be made:-

1. Within two weeks of the start of the trial the control plots were the only ones that lost some of their sand due to the surface erosion (table 8.3). All the treated plots gained small amounts of sand as it was trapped by the vegetation cover.
2. The marram grass had trapped between 43 and 55 cm of sand by February 1989. The probable source of the sand being the erosion of adjacent exposed sand during the high windspeed events of January 27th and 29th.
3. Both erosion and deposition could occur within the same plot, and during the same period of time.
4. The role of the chemical stabilizers was effectively nullified by the massive accumulation of sand on both 27th and 29th January 1989. However, this does not negate the value of the stabilizers since elsewhere erosion rather than deposition occurs and hence stabilizers are essential in order to protect the soil surface.
5. Windspeed was a very effective factor to accumulate or to erode the sand from the site. For example, the massive accumulation of sand on the site due to both the 27th and 29th January 1989 events of windspeeds 15 and 12 m sec^{-1} respectively (table 8.4); whilst, tables (8.5, 8.6, 8.7, 8.9 and 8.10) indicate more sand erosion than accumulation whenever there was high wind

Table 8.3 : Sand Accumulation (A) and Sand Erosion (E) in (mm) for Druridge Bay Field Site 1. (Date: 5th Jan. 1989)

Chemicals	Conc.*	Sand Accumulation and Sand Erosion (mm)					
		Block 1		Block 2		Block 3	
		(A)	(E)	(A)	(E)	(A)	(E)
F.E.	0.2 l m^{-2}	3.0	0.0	2.8	0.0	2.0	0.0
	0.4 l m^{-2}	3.5	0.0	1.8	0.0	2.3	0.0
B.E.	0.5 l m^{-2}	3.0	0.0	4.3	0.0	2.3	0.0
	1.0 l m^{-2}	8.5	0.0	1.0	0.0	3.5	0.0
Aq1	0.66%	1.8	0.0	2.5	0.0	1.8	0.0
	1.00%	1.0	0.0	2.8	0.0	2.5	0.0
Control	.....	0.0	7.3	1.3	4.3	1.5	6.3

Table 8.4 : Sand Accumulation (A) and Sand Erosion (E) in (mm) for Druridge Bay Field Site 1. (Date: 7th Feb. 1989)

Chemicals	Conc.*	Sand Accumulation and Sand Erosion (mm)					
		Block 1		Block 2		Block 3	
		(A)	(E)	(A)	(E)	(A)	(E)
F.E.	0.2 l m^{-2}	547.0	0.0	484.5	0.0	484.0	0.0
	0.4 l m^{-2}	495.3	0.0	493.5	0.0	496.0	0.0
B.E.	0.5 l m^{-2}	443.3	0.0	480.5	0.0	502.5	0.0
	1.0 l m^{-2}	532.0	0.0	539.0	0.0	499.0	0.0
Aq1	0.66%	438.0	0.0	548.5	0.0	482.5	0.0
	1.00%	460.3	0.0	506.8	0.0	518.0	0.0
Control	.....	467.5	0.0	474.3	0.0	526.5	0.0

* Aq1 (%) are on the base of air-dry sand.

Table 8.5 : Sand Accumulation (A) and Sand Erosion (E) in (mm) for Druridge Bay Field Site 1. (Date: 7th Mar. 1989)

Chemicals	Conc.*	Sand Accumulation and Sand Erosion (mm)					
		Block 1		Block 2		Block 3	
		(A)	(E)	(A)	(E)	(A)	(E)
F.E.	0.2 l m^{-2}	0.0	28.8	0.0	26.3	0.0	32.8
	0.4 l m^{-2}	0.8	2.5	49.5	0.0	11.3	3.0
B.E.	0.5 l m^{-2}	1.8	4.5	42.5	0.0	0.0	12.5
	1.0 l m^{-2}	0.0	51.3	0.0	16.8	0.0	32.8
Aq1	0.66%	25.5	0.0	0.0	73.0	0.0	9.3
	1.00%	1.00	8.5	44.3	0.0	0.0	72.5
Control	.....	2.5	18.0	10.0	0.0	0.0	123.8

Table 8.6 : Sand Accumulation (A) and Sand Erosion (E) in (mm) for Druridge Bay Field Site 1. (Date: 28th Mar. 1989)

Chemicals	Conc.*	Sand Accumulation and Sand Erosion (mm)					
		Block 1		Block 2		Block 3	
		(A)	(E)	(A)	(E)	(A)	(E)
F.E.	0.2 l m^{-2}	0.0	0.0	0.0	10.0	0.0	3.8
	0.4 l m^{-2}	0.0	0.0	0.0	1.3	0.0	8.8
B.E.	0.5 l m^{-2}	0.0	0.0	0.0	2.5	0.0	15.0
	1.0 l m^{-2}	0.0	2.5	0.0	6.0	0.0	0.0
Aq1	0.66%	0.0	1.3	0.0	22.5	0.0	13.8
	1.00%	0.0	0.0	0.0	0.0	0.0	11.3
Control	.....	0.0	0.0	0.0	6.3	0.0	141.3

* Aq1 (%) are on the base of air-dry sand.

Table 8.7 : Sand Accumulation (A) and Sand Erosion (E) in (mm) for Druridge Bay Field Site 1. (Date: 20th Apr. 1989)

Chemicals	Conc.*	Sand Accumulation and Sand Erosion (mm)					
		Block 1		Block 2		Block 3	
		(A)	(E)	(A)	(E)	(A)	(E)
F.E.	0.2 l m^{-2}	138.8	0.0	127.5	0.0	76.3	0.0
	0.4 l m^{-2}	145.0	0.0	86.8	0.0	91.3	0.0
B.E.	0.5 l m^{-2}	73.8	0.0	56.3	0.0	95.0	0.0
	1.0 l m^{-2}	66.3	3.8	60.0	0.0	23.8	0.0
Aq1	0.66%	86.3	0.0	0.0	63.8	103.8	0.0
	1.00%	135.0	0.0	98.8	0.0	0.0	15.8
Control	.....	55.0	0.0	57.5	0.0	0.0	83.8

Table 8.8 : Sand Accumulation (A) and Sand Erosion (E) in (mm) for Druridge Bay Field Site 1. (Date: 4th May 1989)

Chemicals	Conc.*	Sand Accumulation and Sand Erosion (mm)					
		Block 1		Block 2		Block 3	
		(A)	(E)	(A)	(E)	(A)	(E)
F.E.	0.2 l m^{-2}	0.0	18.8	2.5	12.5	0.0	1.8
	0.4 l m^{-2}	0.0	15.0	10.0	0.0	0.0	0.0
B.E.	0.5 l m^{-2}	0.0	0.0	7.5	0.0	2.5	0.0
	1.0 l m^{-2}	0.0	20.0	0.0	1.3	0.0	0.0
Aq1	0.66%	0.0	0.0	0.0	12.5	15.0	0.0
	1.00%	0.0	8.8	2.5	0.0	2.5	0.0
Control	.....	1.3	5.0	1.3	0.0	0.0	3.8

* Aq1 (%) are on the base of air-dry sand.

Table 8.9 : Sand Accumulation (A) and Sand Erosion (E) in (mm) for Druridge Bay Field Site 1. (Date: 20th Jun. 1989)

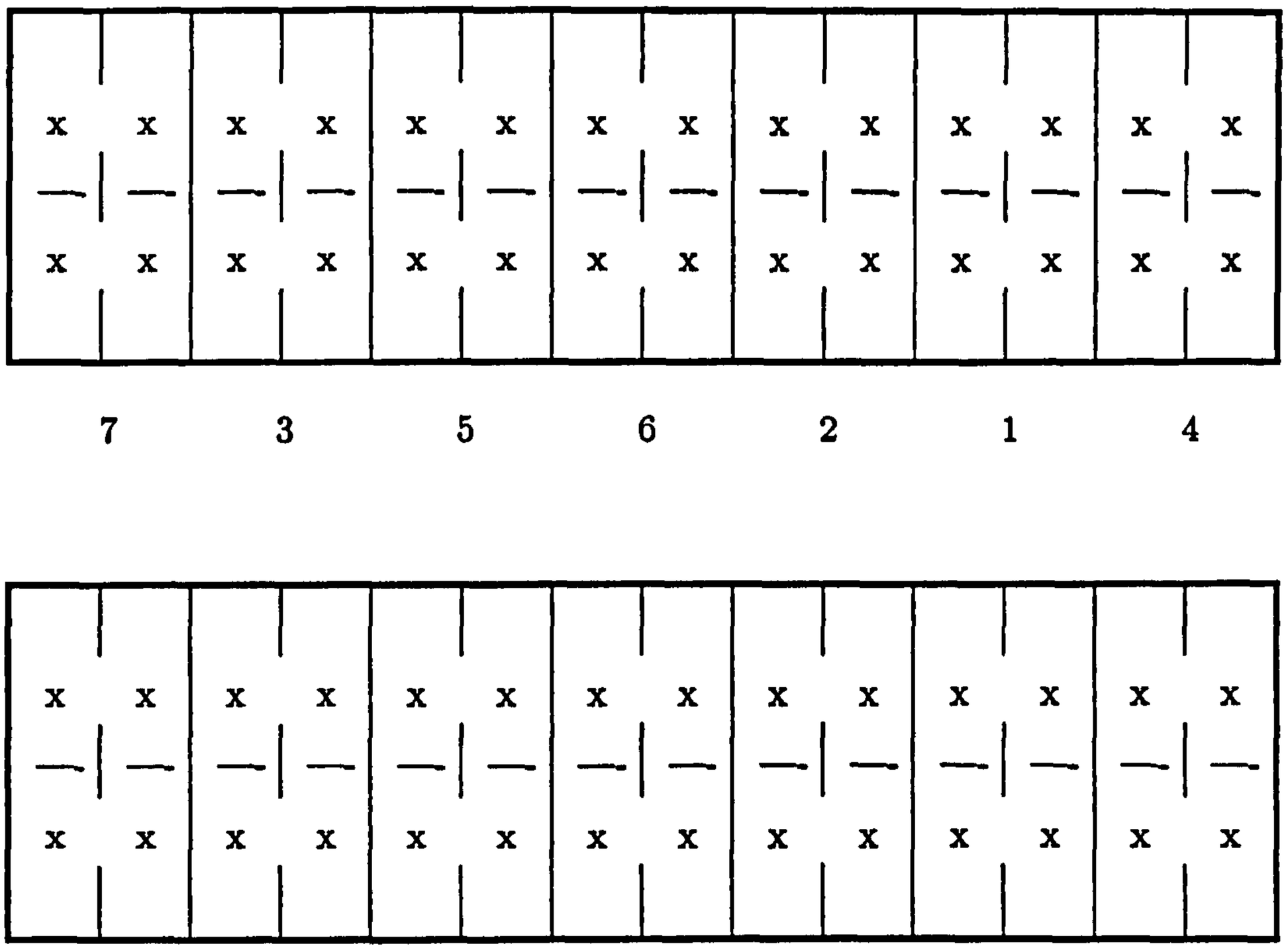
Chemicals	Conc.*	Sand Accumulation and Sand Erosion (mm)					
		Block 1		Block 2		Block 3	
		(A)	(E)	(A)	(E)	(A)	(E)
F.E.	0.2 l m^{-2}	0.0	14.3	2.5	0.0	0.0	6.3
	0.4 l m^{-2}	0.0	7.5	8.8	1.3	0.0	0.0
B.E.	0.5 l m^{-2}	0.0	0.5	1.3	0.0	8.8	0.0
	1.0 l m^{-2}	0.0	25.0	0.0	5.0	0.0	30.0
Aq1	0.66%	3.8	6.8	0.0	55.5	13.8	0.0
	1.00%	0.0	11.3	0.0	0.0	1.3	6.3
Control	.....	0.0	5.5	6.3	0.0	0.0	71.3

Table 8.10 : Sand Accumulation (A) and Sand Erosion (E) in (mm) for Druridge Bay Field Site 1. (Date: 20th Sep. 1989)

Chemicals	Conc.*	Sand Accumulation and Sand Erosion (mm)					
		Block 1		Block 2		Block 3	
		(A)	(E)	(A)	(E)	(A)	(E)
F.E.	0.2 l m^{-2}	0.0	47.5	23.8	2.5	0.0	8.0
	0.4 l m^{-2}	7.5	16.3	0.0	2.0	0.0	7.5
B.E.	0.5 l m^{-2}	6.3	0.0	1.3	2.5	0.0	48.0
	1.0 l m^{-2}	0.0	150.0	0.0	24.3	0.0	0.0
Aq1	0.66%	17.5	0.0	0.0	120.0	0.0	53.8
	1.00%	0.0	2.5	0.0	2.5	0.0	0.0
Control	.....	0.0	10.8	5.0	4.5	0.0	190.0

* Aq1 (%) are on the base of air-dry sand.

Figure 8.22: The Distribution of Sticks in Druridge Bay Field Site 1.



* 1. F.E. 0.2 l m^{-2}; 2. F.E. 0.4 l m^{-2}; 3. B.E. 0.5 l m^{-2}; 4. B.E. 1.0 l m^{-2}; 5. Aq1 0.66%; 6. Aq1 1.0%; 7. Control

events.

6. The plots which fell on the outer edges of the trial area were inevitably subjected to greater erosion than those in the centre, since they lacked the protection of stabilized surfaces on at least one side. The 3 plots of the eastern (right) side (treated with B.E. 1.0 l m^{-2}in block 1; treated with Aq1 0.66% in block 2; and the control in block 3) were the most affected by surface erosion. This was probably due to the following reasons:-

   i. The erosion of a large amount of sand from the adjacent unplanted areas due to children sliding down the unprotected dune surface, causing extensive creep, and small avalanching.
   ii. Natural creep especially when the sand was dry.
   iii. Wind and water erosion.
   ii. The eastern edge of the site was most exposed to the strong eroding winds coming off the sea.

   The next most susceptible plots, were the three along the western edge of the site (control, F.E. 0.2 l $m^{-2}$and Aq1 0.66% respectively) and the second line at the eastern edge (F.E. 0.2 l m-2; B.E. 1.0 l $m^{-2}$and Aq1 1.0% respectively).

7. Apart from the three eastern most plots, the sand that accumulated during the two January events was never removed in sufficient quantities to exhume the chemically stabilized surfaces at any time during the 9 months recording period.

8. It is important to mention that, no more significant erosion were occurred in this site for another year when a massive destruction of the site took place by avalanching the eastern most plots. This was due to the successive destructions of the adjacent unprotected area caused by the people, surface creep and both wind and water erosion. Therefore, for successful stabilization of the dunes, the area must be planted and must then treated with a

suitable chemical stabilizer (at least in strips). Notices should be erected to inform people that scientific research is under progress with fences to prevent vandalism occurring.

8.6 Effect of Soil Chemical Stabilizers on Sand Infiltration Rate and Accumulated Infiltration

8.6.1 Techniques, Materials and Methods

At site 1, a new block 7 m long and 1 m wide of newly deposited sand was divided into 7 plots each 1 m^2. On a random basis the stabilizers F.E. (0.2 and 0.4 l m^{-2}); B.E. (0.5 and 1.0 l m^{-2}) and Aq1 (0.66% and 1.0%) and the control were applied to the plots. After the application of the chemicals, the plots were left for 72 hrs in order to dry.

Three methods of estimating soil water infiltration characteristics have been recognised (Michael, 1978). They are: (a) the use of cylinder infiltrometers, (b) measurement of subsidence of free water in a large basin, and (c) estimation of accumulated infiltration from the water front advance data. Of these three methods the most frequently used and simplest technique is the use of cylinder infiltrometers. Thus the cylinder infiltrometers method was adopted for this study.

In order to overcome the variability in the infiltration data due to the uncontrolled lateral movement of water from the single cylinder after the wetting front reaches the bottom of the cylinder*, a 50 cm long plastic cylinder was driven 25 cm into the sand. The cylinder had an inside diameter of 10.4 cm. A longitudinal 20 cm window was made in the cylinder, and a centimetric scale fixed parallel to the side of the window, and this enabled water level measurements to be recorded. The cylinder base was sharpened in order to ease its insertion into the sand and to reduce damage to the surface layer. The cylinder was driven into the sand by

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* *A standard double ring infiltrometer method was not used because of the slope and the practicality of transporting enough water to the site.*

an ordinary hammer striking on a wooden plank placed on top of the cylinder in order to prevent any damage to the upper edge of the cylinder. The experimental set-up used in this study is illustrated in photo (8.34).

Plate 8.34: The Field Work Infiltration Rate Set-Up.

Water was poured carefully into the cylinder to a depth of 20 cm (care was taken to avoid any disturbance of the surface). The water level was topped up to 20 cm as quickly as possible after each measurement so that a constant average infiltration head could be maintained (Michael, 1978). A stop clock was used to note the elapsed time while the infiltration measurements were taken.

All treatments were tested in triplicate. The input water depths as a function of time were later used for the calculation of the infiltration rates (cm hr^{-1}) and accumulated infiltrations (cm).

The objectives of this study were:-

i. to study the effect of the soil chemical stabilizers on the infiltration rate of Druridge Bay sand dunes under the field conditions.

ii. to compare the infiltration rates measured under the field conditions with those already measured in the laboratory.

8.6.2 Results and Discussions:

A knowledge of the infiltration rates of the field plots treated with the various sand chemical stabilizers is of great importance since infiltration is the main entry process of water into the soil, without which seeds and plants would fail. Thus field infiltration data will provide yet another parameter by which to compare the different treatments.

The effect of the chemical stabilizers on the infiltration rate of Druridge Bay sand are illustrated in figures (8.23 - 8.25) and their effect on the accumulated infiltration of the sand are illustrated in figures (8.26 - 8.28). In all cases the figures are the mean of 3 replicates.

As reported from the laboratory experiments (chapter 5 section 5.1.2.3), the results show that all three stabilizers reduced both infiltration rate and accumulated infiltration of the sand when compared with the control. In all these cases increased chemical concentration caused a further decrease in both infiltration characteristics. Aq1 1.0% causes the greatest decrease in infiltration rate and accumulated infiltration. But, nevertheless even this stabilizer has an infiltration rate in excess of the minimum acceptable infiltration rate of 0.25 cm hr^{-1} (Richards, 1969).

The infiltration rates in both control sand samples and those with various chemical treatments indicate a sharp reduction within the first 6 minutes before they reach their steady states. The factors responsible for the decreases in the infiltration rate in the early stages of the test before it approaches its constant value and the reductions due to the application of some chemical materials as a surface mulches have been discussed in detail in chapter 5 section 5.1.2.3.

When the results of the field and laboratory tests are compared it is apparent that the treatments behave in the same way in both situations (figures 8.29 - 8.34).

Fig. 8.23: Effect of F.E. on Infiltration Rate in Druridge Bay Sands (Field Test).

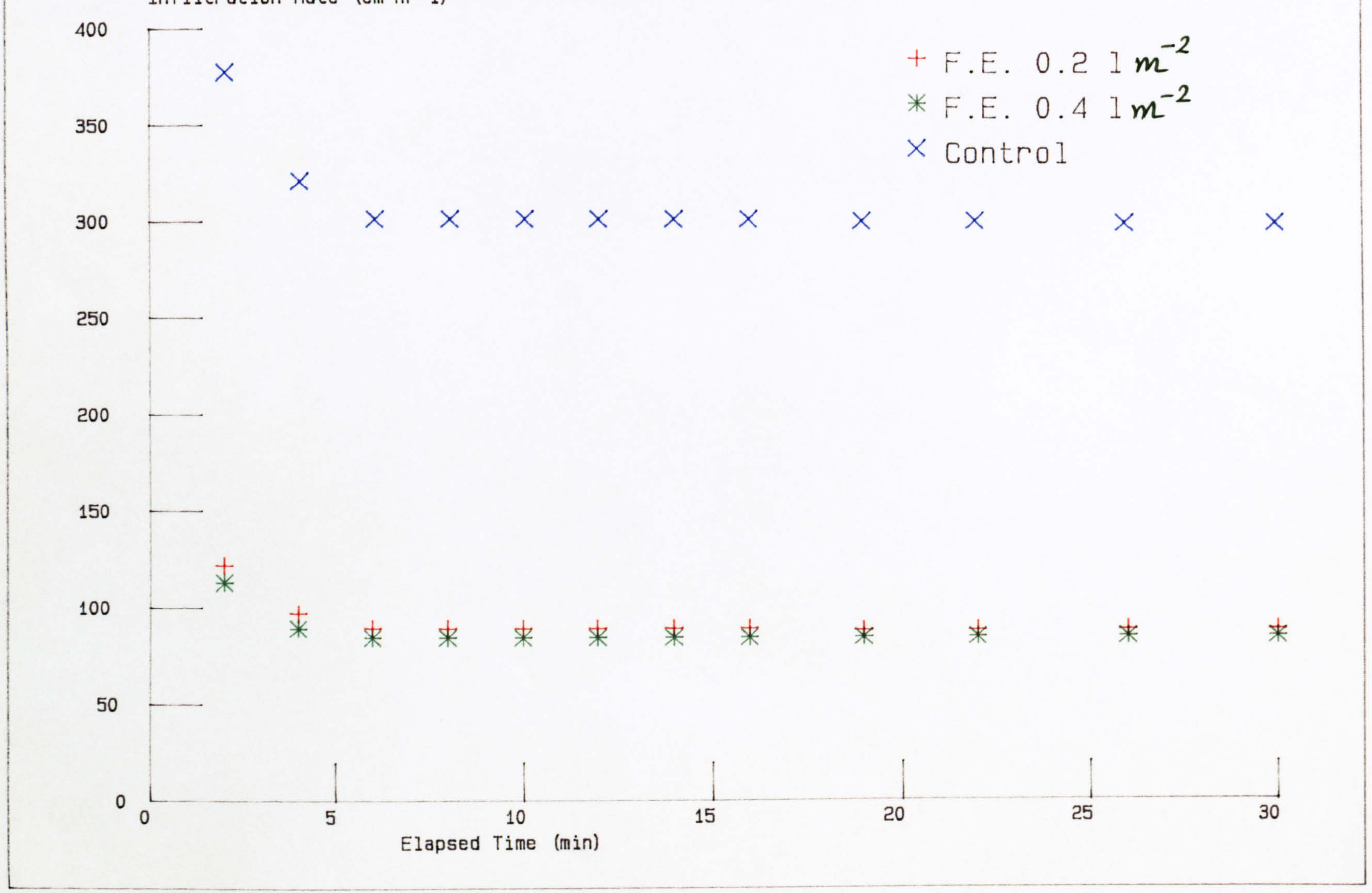


Fig. 8.24: Effect of B.E. on Infiltration Rate in Druridge Bay Sands (Field Test).

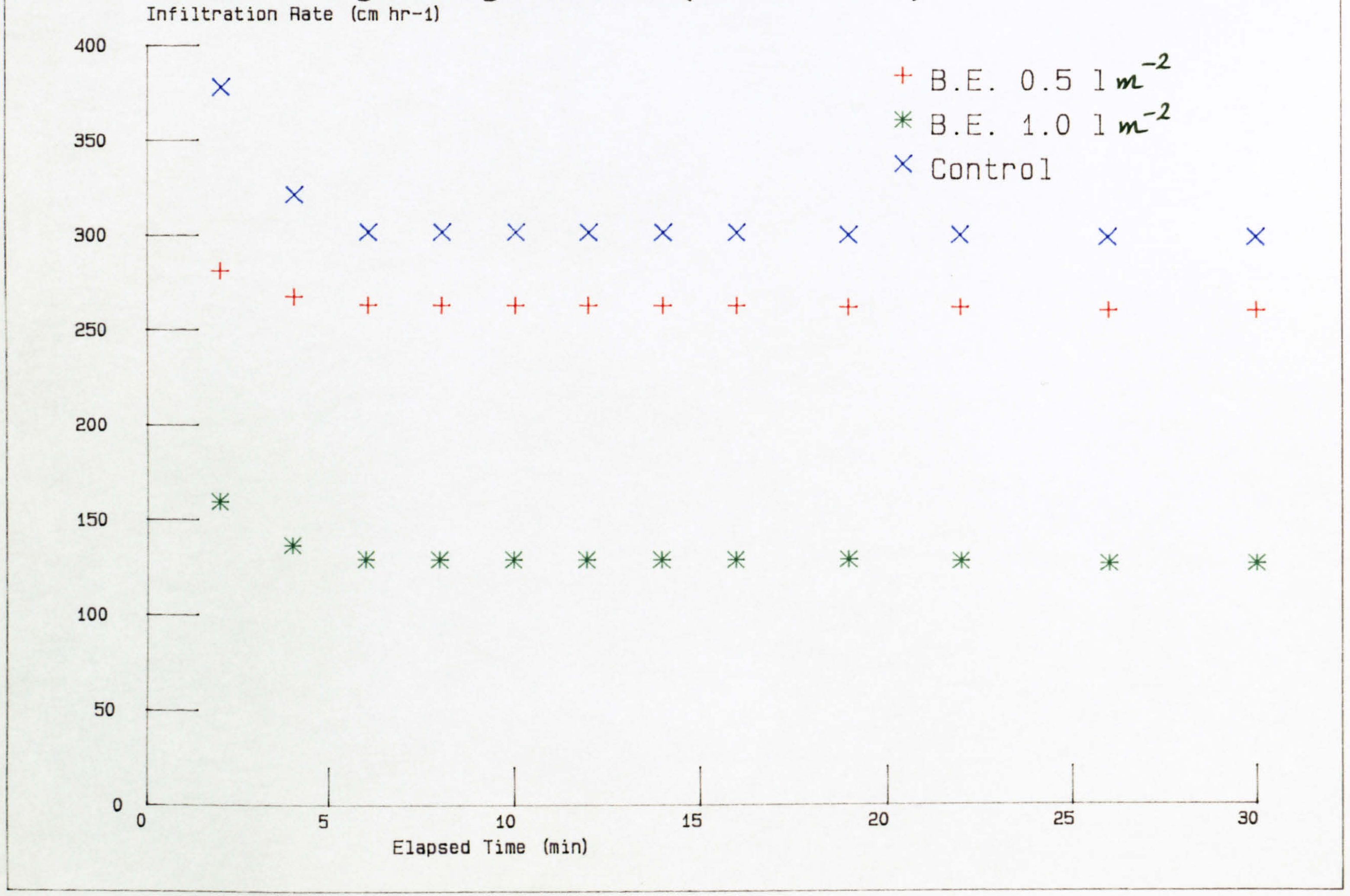


Fig. 8.25: Effect of Aq1 on Infiltration Rate in Druridge Bay Sands (Field Test).

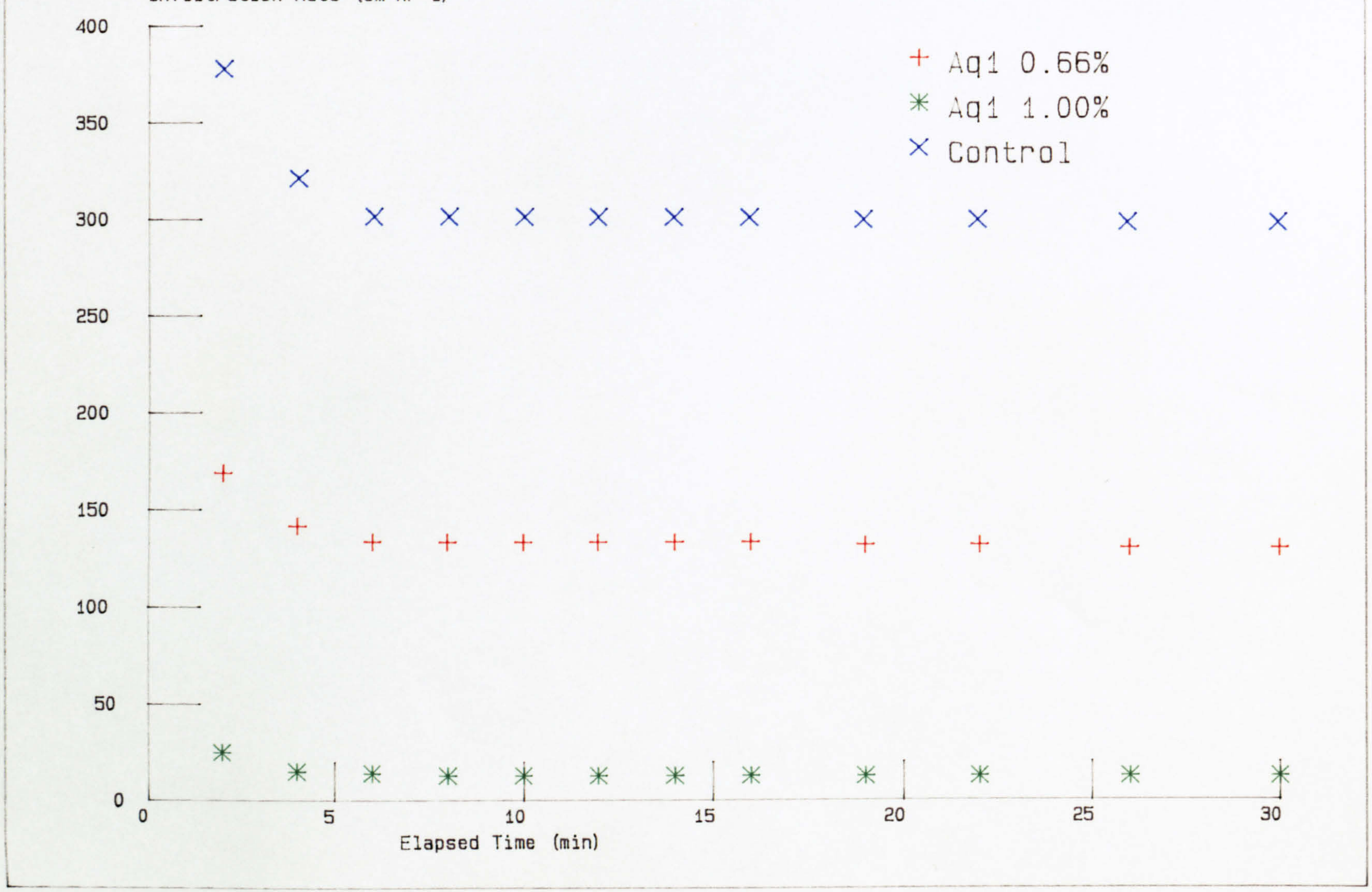


Fig. 8.26: Effect of F.E. on Accumulated Infiltration in Druridge Bay Sands (Field Test).

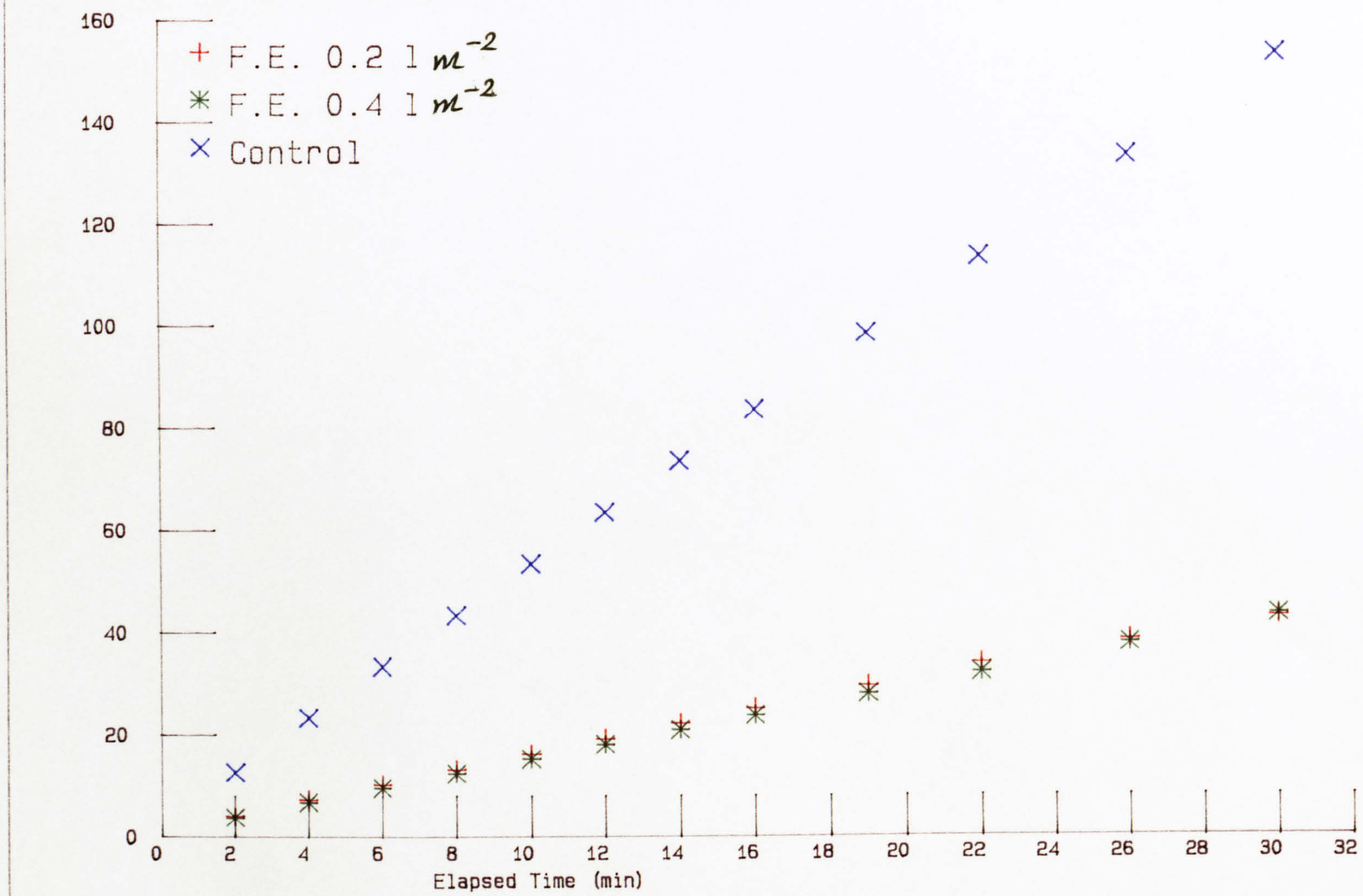


Fig. 8.27: Effect of B.E. on Accumulated Infiltration in Druridge Bay Sands (Field Test).

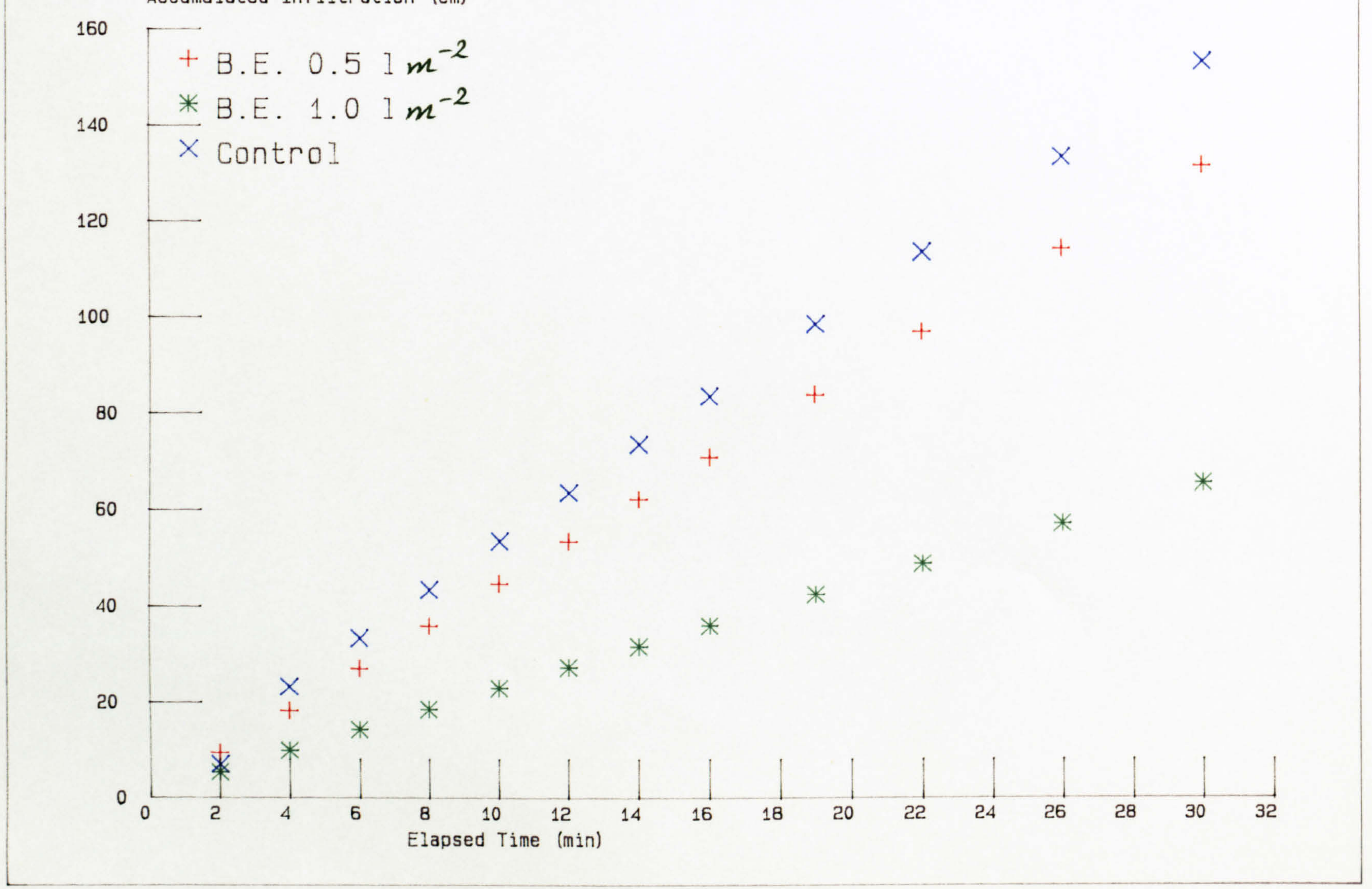


Fig. 8.28: Effect of Aq1 on Accumulated Infiltration in Druridge Bay Sands (Field Test).

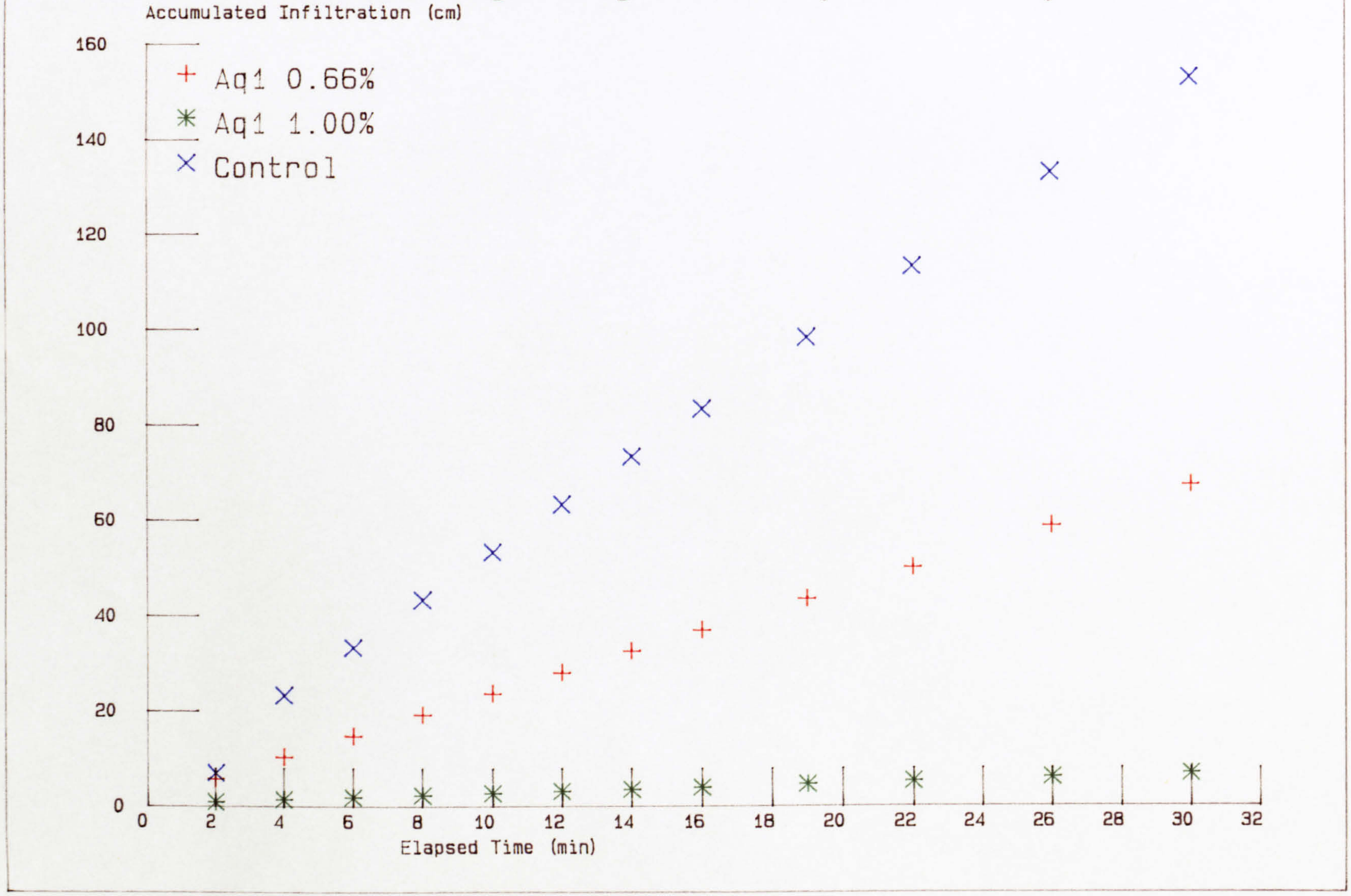


Fig. 8.29: Effect of F.E. on Infiltration Rate in Druridge Bay Sands (Field and Lab. Tests).

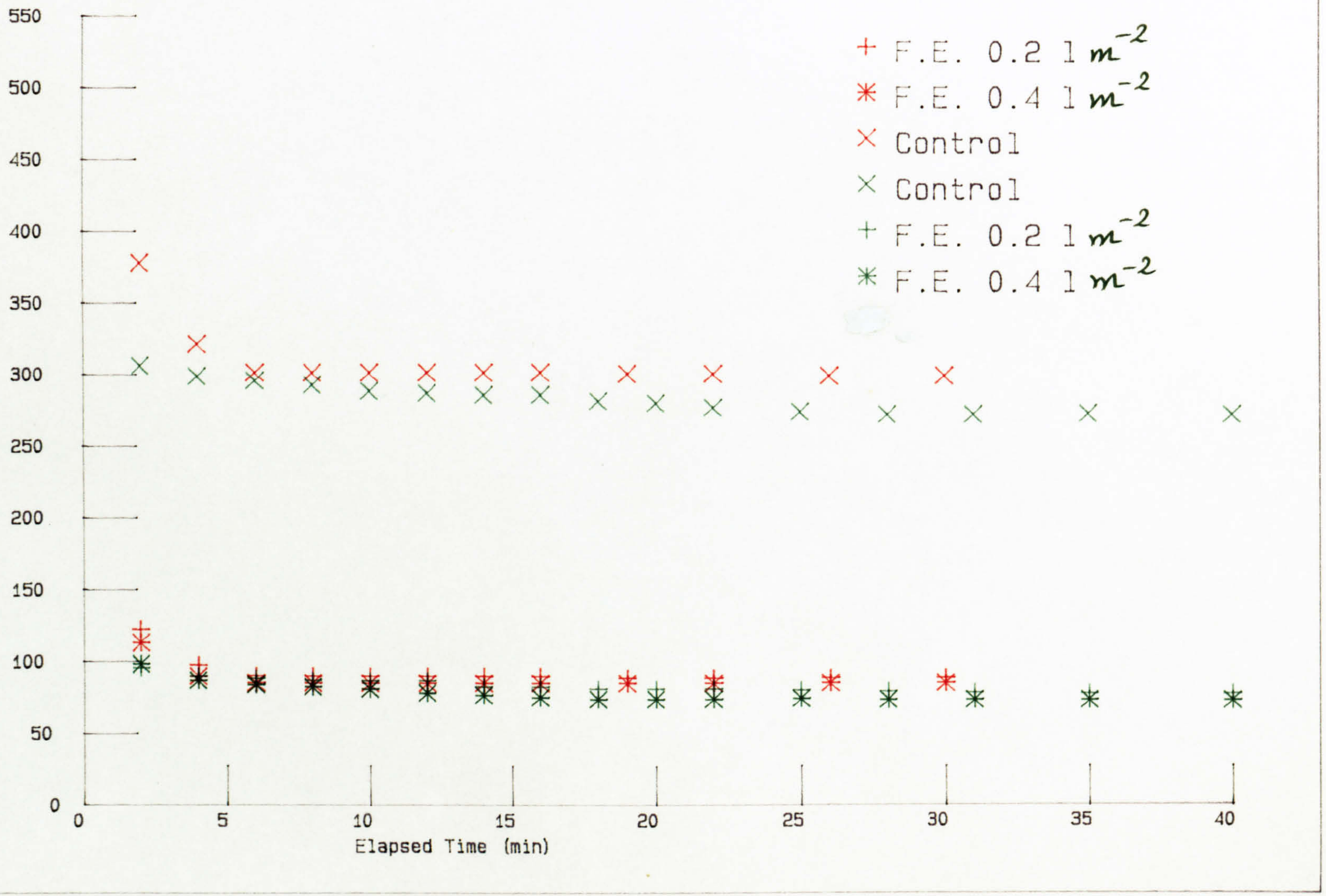


Fig. 8.30: Effect of B.E. on Infiltration rate in Druridge Bay Sands (Field and Lab. Tests).

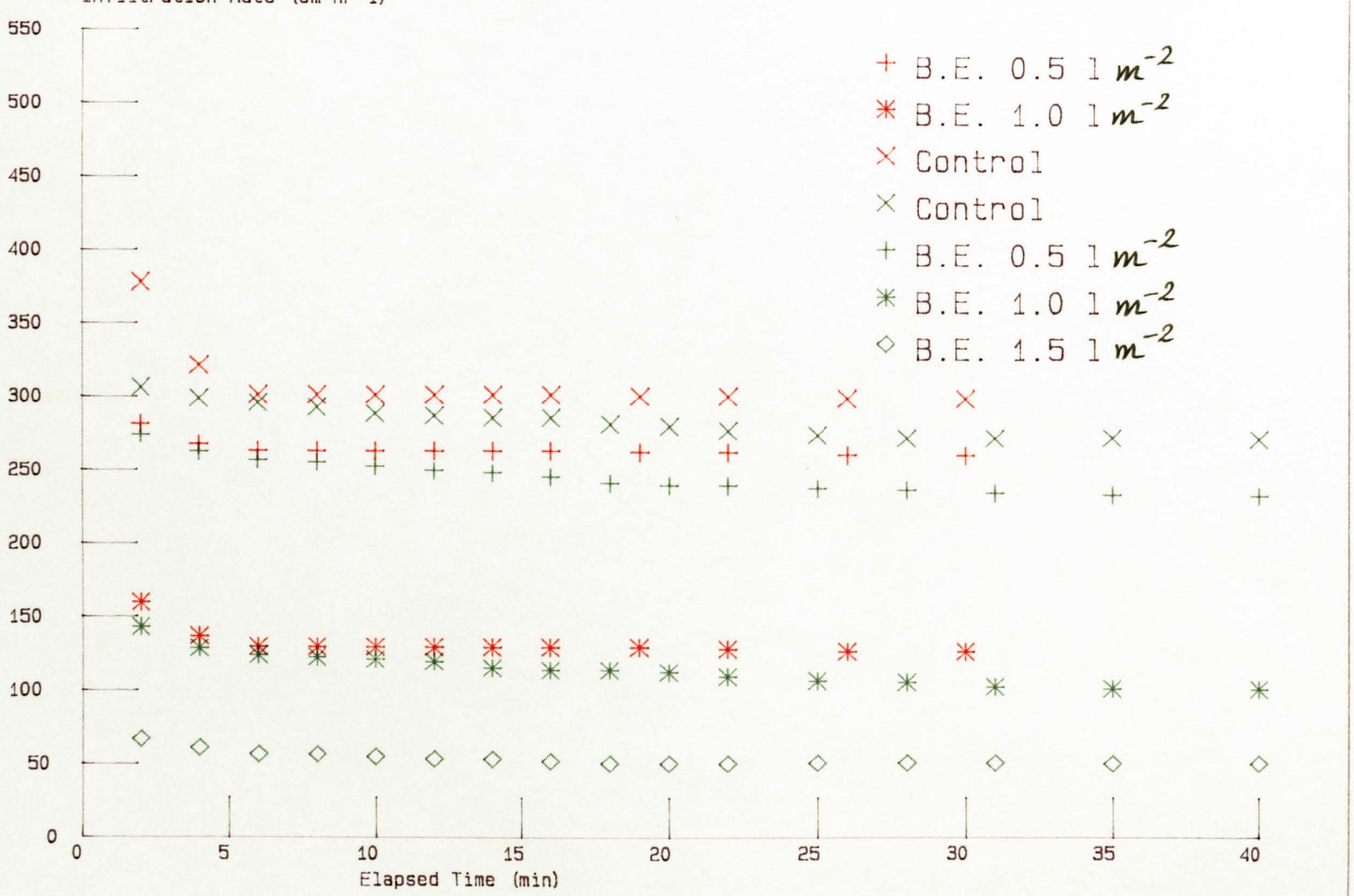


Fig. 8.31: Effect of Aq1 on Infiltraion Rate in Druridge Bay Sands (Field and Lab. Tests).

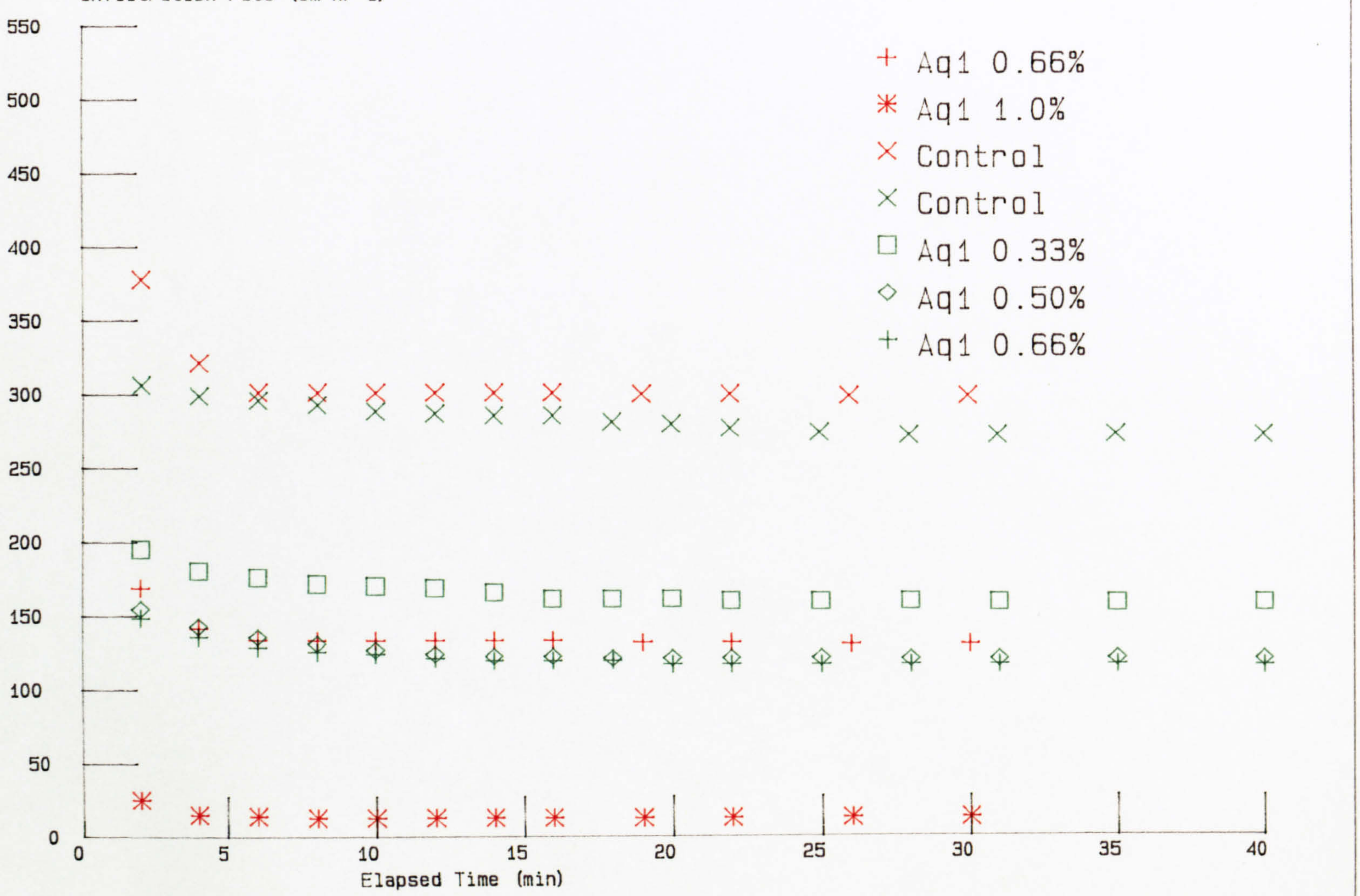


Fig. 8.32: Effect of F.E. on Accumulated Infiltration in Druridge Bay Sands (Field and Lab. Tests

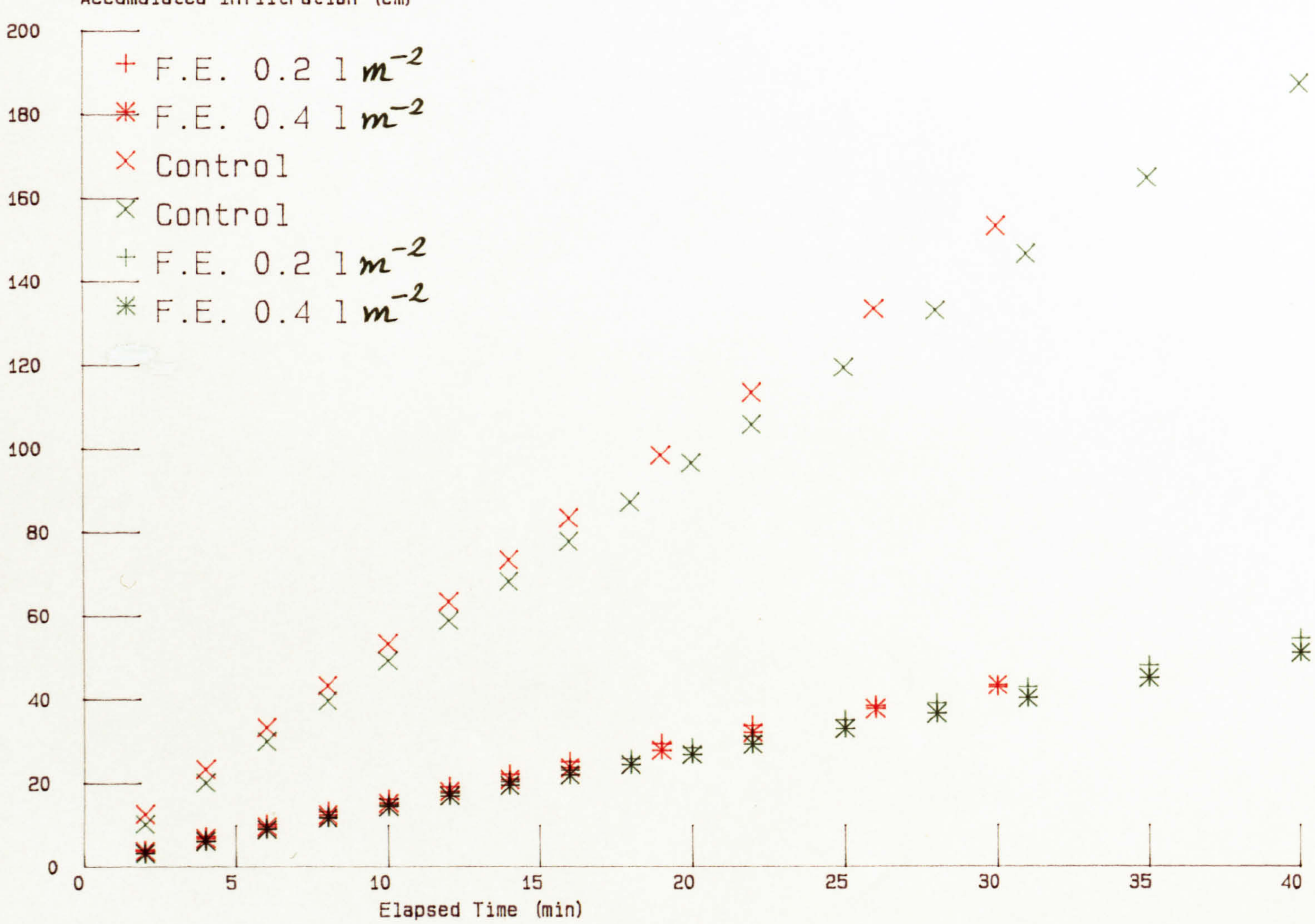


Fig. 8.33: Effect of B.E. on Accumulated Infiltration in Druridge Bay Sands (Field and Lab. Tests

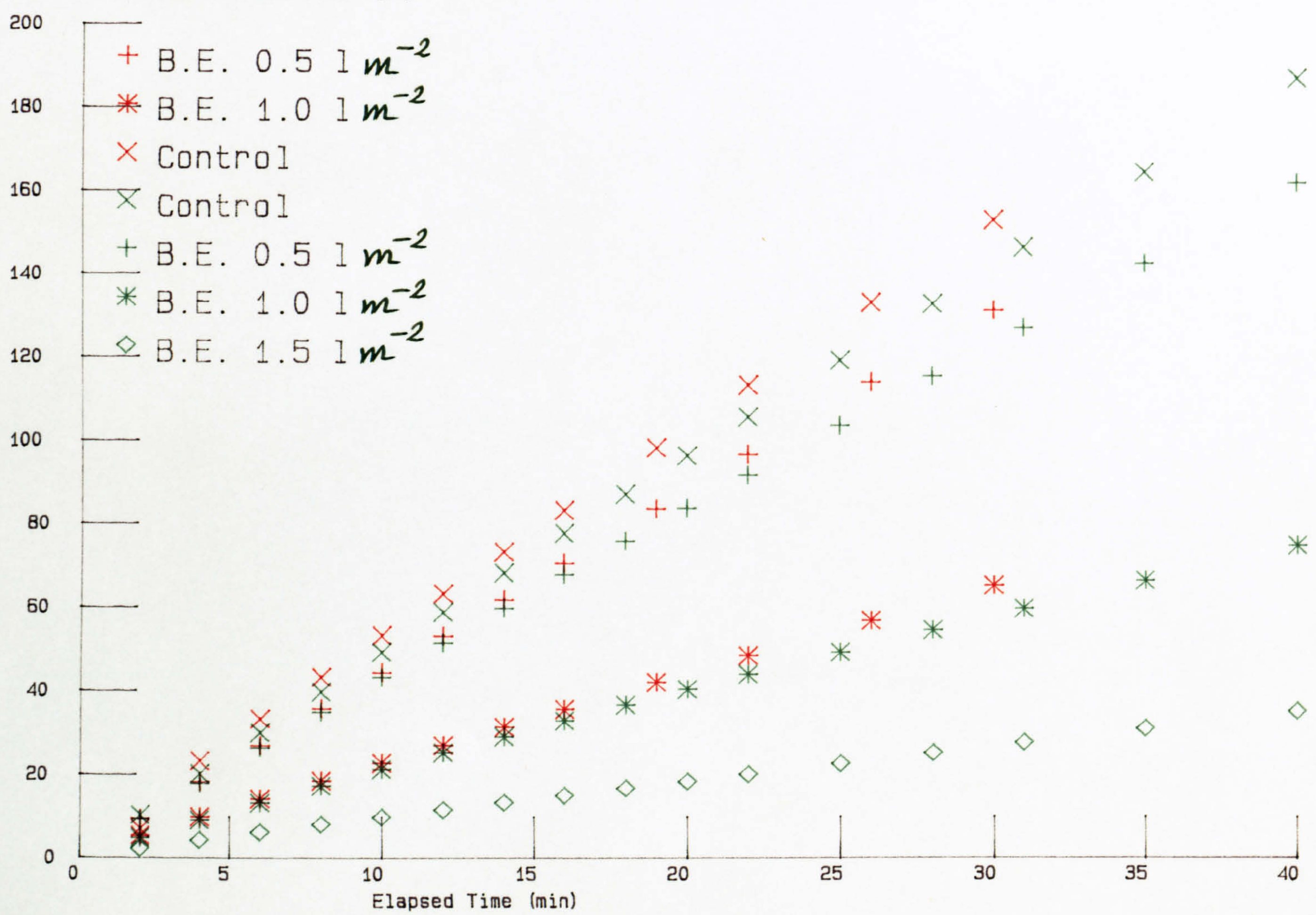
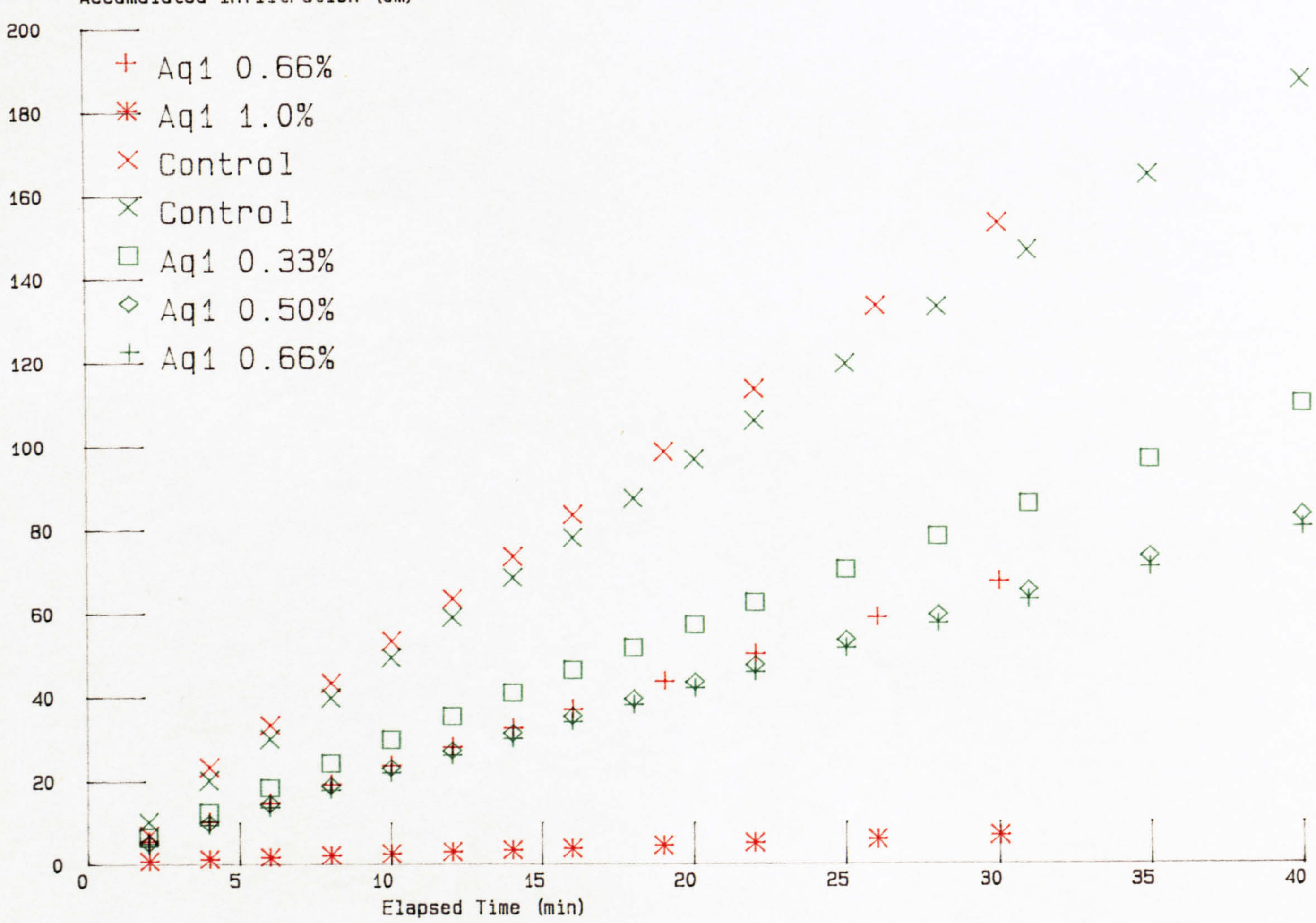


Fig. 8.34: Effect of Aq1 on Accumulated Infiltration in Druridge Bay Sands (Field and Lab. Tests



The field sites reach a steady state of infiltration much faster than the laboratory samples (6 minutes as compared to 25 minutes). This is probably due to the higher field moisture contents (see table 8.11 section 8.7.3), and consequently the faster stratification between the sand particles under the field conditions compared with the laboratory ones of air-dry sand. Furthermore, both infiltration rate and accumulated infiltration measurements under the field conditions are higher than those under the laboratory conditions. These are probably due to the higher sand surface primary moisture content in the field during the application of the chemical stabilizers (4.3%) comparing with the air-dry sand samples used in the laboratory. The higher the surface moisture content, the deeper the chemical can go, and consequently the lower the chemical concentration will be. It is for this reason that Aq1 1.0% was permeable under the field conditions; but impermeable when investigated under the laboratory conditions.

8.7 Effect of Soil Chemical Stabilizers on the Modulus of Rupture

8.7.1 Theoretical Basis

The modulus of rupture is a measure of the breaking strength of a material e.g. artificial soil crusts (Kirkham et al., 1959). Kirkham et al. used the Brasilian method for the determination of the modulus of rupture on undisturbed silty clay loam and silty loam soils core samples. In this method, the core sample is placed on its side on a horizontal plate (figure 8.35) and a crushing force F is applied through another horizontal plate above the core. When the force F becomes sufficiently large, the sample ruptures along a vertical plane passing through the axis of the core. The force which causes the rupture is related to the modulus of rupture strength S of the sample through the formula:

$$F = \frac{\pi}{2} SDL \qquad 8.1$$

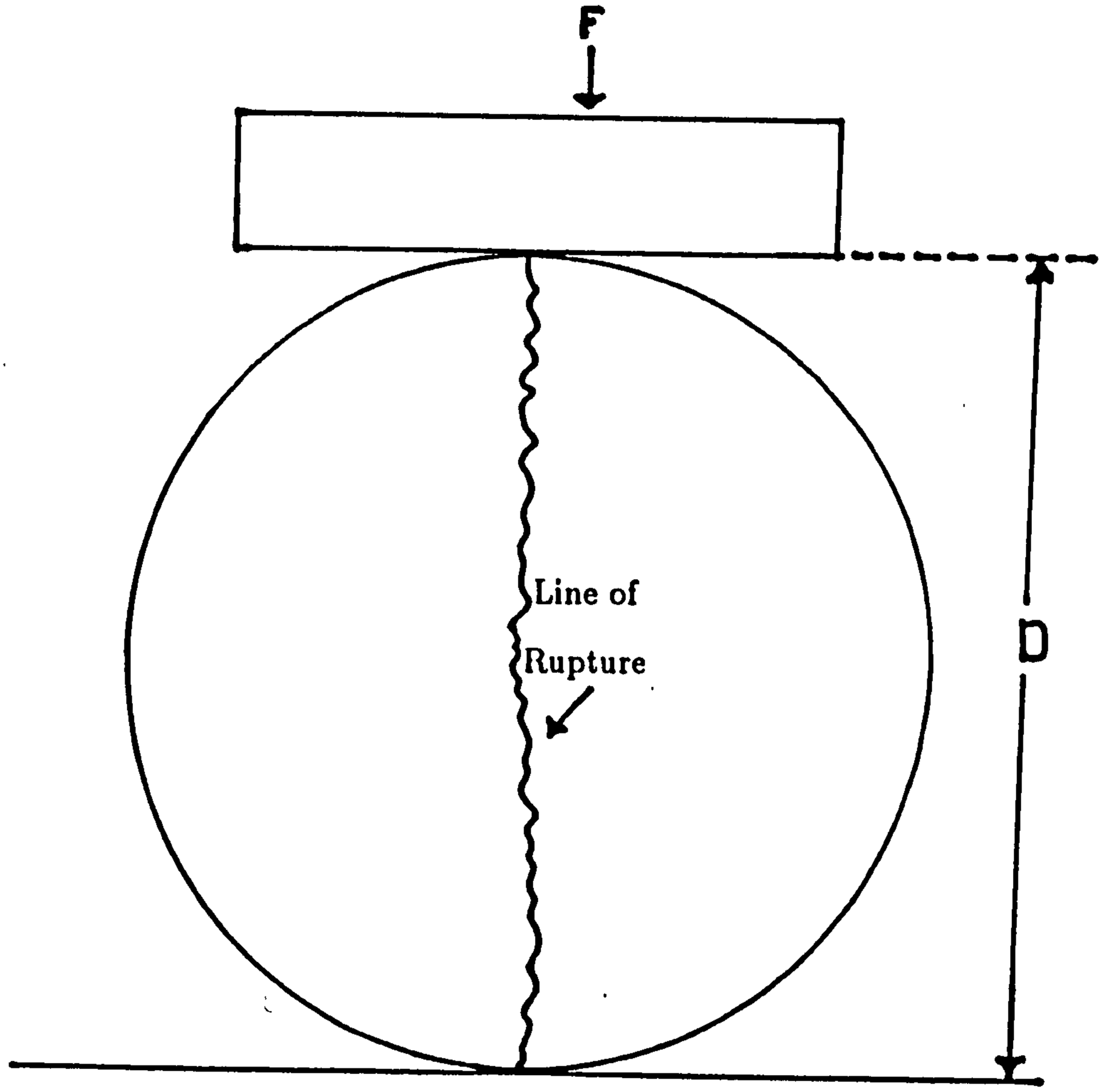


Figure 8.35: Geometry for Modulus S of Rupture Determination of a Soil Core Sample by Use of Equation 8.2; Length of the Core is L. (After Kirkham et al., 1958).

in which D is the diameter of the sample and L it's length. That is:

$$S = \frac{2F}{\pi DL} \qquad 8.2$$

if F is in kg and D and L in cm, then S is in kg cm^{-2}. Sometimes modulus of rupture is expressed in units of bars: one bar = 1.023 kg cm^{-2}.

Richards (1953) used modulus of rupture as an index for soil crusting. Many factors affect the modulus of rupture of soils e.g. clay content, organic matter

content, wetting process and the application of the chemical conditioners or stabilizers. For example, Rogowski et al. (1968) indicated that the modulus of rupture of soil aggregates increases as clay content increases, when measured in an unconfined compression apparatus.

Kemper et al. (1974) indicated that the modulus of rupture is affected by the method and rate of wetting and degree of water saturation. In Iraq, Salih et al. (1988) studied the effect of wetting under vacuum and capillary rise under atmospheric pressure on the modulus of rupture of six calcareous soils of varying texture and aggregate stability. The results showed increases in the modulus of rupture when wetting under vacuum compared with wetting by capillary rise under atmospheric pressure in the poorly structured soils, the results were reversed for the soils with the stable structures.

Information on the effect of soil chemical stabilizers on the modulus of rupture of soils is rare. Applications of chemical materials as surface mulches could increase or decrease the modulus of rupture of the soil depending on the nature of the soil. For example, in the soils suffering from a hard surface crust, chemical conditioners should reduce the modulus of rupture of the surface layer allowing increased in seed germination and subsequently plant growth (Jassim, 1983). Pla (1975) found that the modulus of rupture in surface samples of six Venezuelan soils treated with 0.16% PAM and 1.25% bitumen emulsion (on dry weight bases) were lower than the untreated ones. Thus, from this limited information, if chemical stabilizers are to succeed in preventing both wind and water erosion, they must increase the modulus of rupture of the soil surface.

In this study the applications of the chemical stabilizers F.E. (0.2 and 0.4 l m^{-2}); B.E. (0.5 and 1.0 l m^{-2}) and Aq1 (0.66% and 1.0%) as surface mulches would be expected to increase the modulus of rupture of the top loose sand layer in order to protect it against both wind and water erosion.

8.7.2 Techniques, Materials and Methods

The same field plots used for the measurements of both infiltration rate and accumulated infiltration as indicated in section 8.6, were used for the measurements of both modulus of rupture and the sand moisture content under the effect of the various chemical treatments.

The H-60 Inspection Vane Borer manufactured by (GEONOR A/S P.O.Box 99, R 0 A - Oslo 7, Norway) was used to measure the modulus of rupture of the sand at the following depths: 0 - 5 cm, 10 - 15 cm, 25 - 30 cm and 55 - 60 cm. Three measurements were taken at each depth. The Vane Borer used is shown in diagram 8.36.

The range of the instrument is from 0 to 26 t m^{-2} when the three different sizes of vanes are used. The accuracy of the instrument should be within $\mp 10\%$ of the reading. In order to avoid the effect of friction between the sand and the 0.5 m long rod connected between the Vane-Shaft and the Lower Part of the instrument, the remoulded shear strength measurements were substracted from all the readings at both 25 - 30 cm and 55 - 60 cm depths.

Three sand samples from each depth under the effect of all treatments were taken by 60 cm long auger at the time of measuring the modulus of rupture. The sand samples were later oven-dried at 105°C to find out if any relationship existed between the modulus of rupture measurements and the sand moisture contents.

8.7.3 Results and Discussion

Table 8.11 illustrates the results of both modulus of rupture measurements and sand moisture content determinations. Figure 8.37 illustrates the correlation between the sand moisture content and the modulus of rupture at the depths 10 - 15 cm, 25 - 30 cm and 55 - 60 cm under all seven treatments. The measurements given in table 8.11 and used in figure 8.37 are the means of three replicates. From the results presented in table 8.11 and figure 8.37 the following can be deduced:-

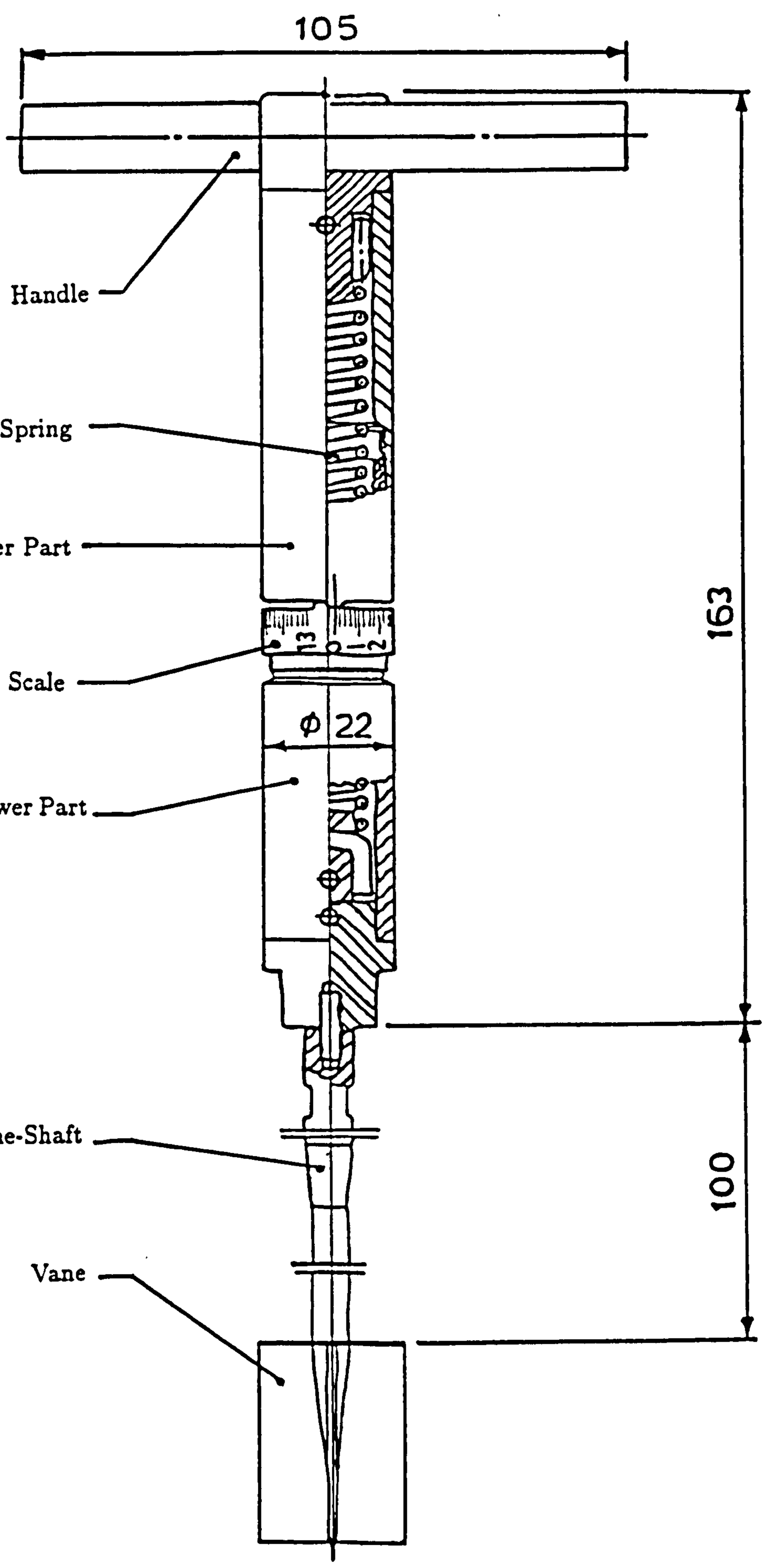


Figure 8.36: The Inspection Vane Borer Used for the Measurements of Modulus of Rupture.

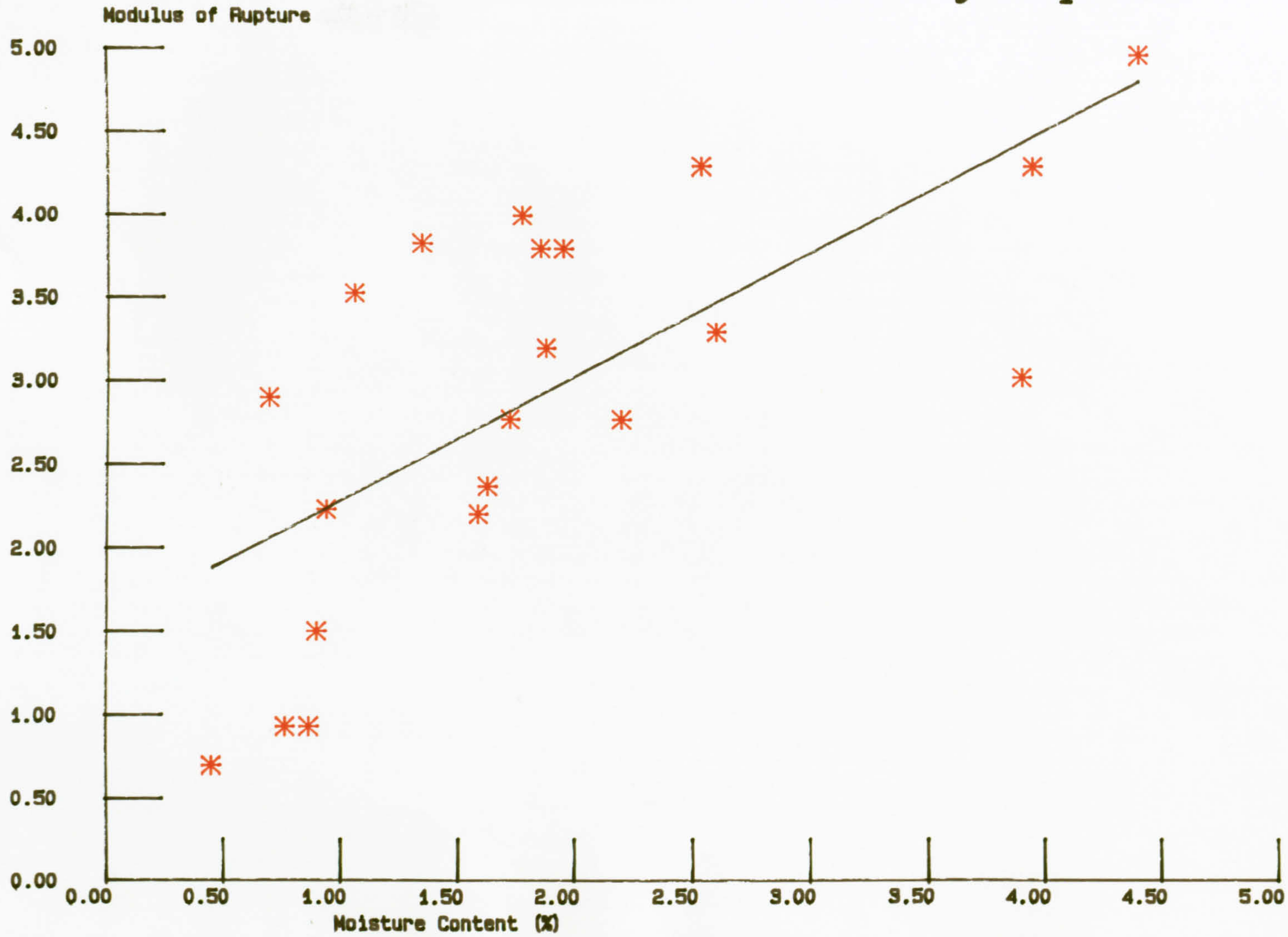
Table 8.11 : Effect of Various Chemical Stabilizers on the Sand Moisture Content (MC%) and the Modulus of Rupture (MOR) (t m^{-2}) Measurements in Druridge Bay Sand Dunes - Field Tests.

Chemicals	Conc.*	Moisture Content and Modulus of Rupture Measurements at Depths:							
		0 - 5 cm		10 - 15 cm		25 - 30 cm		55 - 60 cm	
		MC%	MOR	MC%	MOR	MC%	MOR	MC%	MOR
F.E.	0.2 l m^{-2}	2.32	2.2	4.60	5.6	1.98	2.7	2.64	4.9
		2.75	2.1	3.92	5.0	1.90	2.8	2.33	4.1
		2.98	2.5	5.46	4.6	1.70	2.3	1.97	4.3
F.E.	0.4 l m^{-2}	2.61	3.0	4.14	3.0	0.58	0.7	0.99	3.9
		3.17	2.0	3.52	2.9	1.12	0.8	0.56	3.1
		2.75	2.4	4.07	3.2	0.87	1.3	1.63	3.6
B.E.	0.5 l m^{-2}	0.56	0.5	2.64	3.2	0.76	2.5	2.01	4.7
		1.14	0.9	1.09	2.1	1.15	2.5	1.78	3.5
		1.75	1.0	2.87	3.0	0.87	1.7	1.78	3.2
B.E.	1.0 l m^{-2}	1.48	2.0	0.77	1.8	0.28	0.5	1.35	4.0
		2.10	2.0	1.45	2.3	0.43	0.7	1.24	3.6
		2.11	2.2	2.63	3.0	0.63	0.9	1.46	3.9
Aq1	0.66%	1.27	1.2	2.22	1.8	1.98	2.8	1.56	3.5
		2.39	1.2	3.26	4.8	1.87	2.9	1.88	4.7
		1.53	2.3	2.34	3.3	1.31	2.6	1.89	3.8
Aq1	1.00%	1.31	3.2	0.89	1.6	1.05	0.9	0.45	2.1
		1.73	2.4	0.88	1.0	0.45	1.1	0.80	3.5
		0.98	3.4	0.89	1.9	0.77	0.8	0.81	3.1
Control	.....	0.94	0.2	4.28	5.1	1.97	2.8	2.35	4.4
		0.74	0.2	4.19	5.4	1.89	3.2	2.42	4.4
		1.27	0.4	4.76	4.4	1.78	3.6	2.88	4.1

* Aq1 (%) are on the base of air-dry sand.

1. The statistical analysis indicated a significant relationship between the sand moisture content and the modulus of rupture measurements. The calculated (r) value (0.691) for the above mentioned relationship was higher than the tabulated (r) value (0.549) at the level of significant 1% giving a significant positive correlation between modulus of rupture and moisture content (Gheyi and VanBladel, 1975).

Fig. 8.37: Correlation Between the Sand Moisture Content and the Modulus of Rupture.



2. The moisture contents in the first 5 cm depth increased with the increase in the chemicals concentrations (except in the cases of the surface layers treated with Aq1 0.66% and 1.0%). The increases in the moisture content were due to the reduction in water evaporation from the plots treated with the chemicals, the higher the concentration of chemical the greater the reduction in water evaporation. The low moisture content under Aq1 1.0% was due to the extremely low infiltration rate in this layer compared with Aq1 0.66%.
3. Modulus of rupture measurements in the surface layer of treated plots increased with the increase in the chemical concentrations used.
4. All treatments had both higher moisture contents and higher modulus of rupture readings in the surface layer when they were compared with the control. The lower moisture content in the untreated surface layer was because of the high water evaporation from that layer in comparison with the treated ones; and the lower modulus of rupture measurement was due to a lack of any surface crust.
5. Below the surface layer moisture contents increase, the greatest increase is in the control, followed by the lower concentrations of F.E.; Aq1 and B.E., the lowest moisture contents were in the Aq1 1.0% plot. Thus as chemical concentrations reduce infiltration rates so subsurface moisture contents fall.
6. Modulus of rupture readings at 10 - 15 cm, 25 - 30 cm and 55 - 60 cm depths under the low chemical concentrations were higher than the ones under the high concentrations. This is almost certainly due to the higher moisture contents within these layers beneath the low chemical concentrations (point 5 above).
7. Modulus of rupture readings under all treatments at 55 - 60 cm depth were higher than those at the other three depths 0 - 5 cm, 10 - 15 cm and 25 - 30 cm although the moisture content at that layer was not always higher. This could be because of the increased natural compaction between the sand

particles at this depth.

Thus whilst the highest concentrations of the stabilizers produce the most resistant surfaces they have an adverse effect on the underlying sand by reducing its moisture content as a direct result of lowering the surface infiltration rate.

8.8 Conclusions

For successful sand dune stabilization at Druridge Bay, the area must first be planted with marram grass or a suitable alternative and must then be treated with a suitable chemical stabilizer (at least in strips). Both the vegetation cover and the surface stabilizer will protect the sand surface against wind erosion and probably water erosion as well. Notices should be erected to inform people that scientific research is under progress with fences to prevent vandalism occurring.

With the area being accessible to the public and part being both an SSSI and Nature Reserve the choice of chemical stabilizer is important, since 'aesthetic' values as well as practicality and cost have to be considered. Thus, bitumen emulsions, whilst being very effective can be rejected as a possible stabilizer in this instance, as larger areas of 'black sand' will not be acceptable to the public. Thus colourless Ferquatac emulsions or Aquapol have to be considered to be the most suitable stabilizers in these circumstances.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

The long term stabilzation of sand dunes has been reported (eg. Zoght, 1978) to be achieved most effectively by establishing a vegetation cover. In order to establish a vegetation cover in these very unstable environments, it is essential that the sand surface remains stable whilst vegetation becomes established, since any disruption of the surface in the early stages of plant growth will inevitably lead to the death of the plant, or, in extreme cases its complete removal. There are a number of techniques that can be used to achieve this initial surface stabilization, for example the use of organic or chemical mulches.

The focus of this thesis has been on the suitability of a number of new and established chemical mulches to act as sand dune stabilzers in two contrasting environments, one a coastal sand dune system at Druridge Bay in North East England and the other an extensive dune system at Baiji in central Iraq. Of the eleven chemicals chosen for the study, six apparently established stabilizers - polyvinyl alcohol 14,000 (PVA1) (0.2% and 0.4%); polyvinyl alcohol 125,000 (PVA2) (0.2% and 0.4%); polyethylene glycol 4000 (PEG3) (0.2% and 0.4%); polyethylene glycol (PEG4) (0.2% and 0.4%); bitumen emulsion A1-55 (B.E.) (0.5 and 1.0 l m^{-2}) and Vinamul 3277 (V2) (0.05 and 0.10 l m^{-2}) were selected following an extensive literature review (see chapter 5), the results of studies of these six chemicals provided a base from which to compare the effectiveness of five new chemical mulches: Ferquatac emulsion RB-50 (F.E.) (0.2 and 0.4 l m^{-2}); Vinamul 3270 (V1) (0.05 and 0.10 l m^{-2}); Vinamul 18207 (V3) (0.05 and 0.10 l m^{-2}); Aquapol 35-0019 (Aq1) (0.33% and 0.66%) and Aquapol 35-0031 (Aq2) (200 and 250 gm m^{-2}).

The effectiveness of any chemical mulch as sand dune stabilizer can be assessed on the following criteria: prolonged resistance to both wind and water

erosion, permeability, non-toxicity to germinating seeds or seedlings and the ability to produce stable aggregates. These properties were tested for each of the eleven chemical treatments by means of extensive laboratory, greenhouse, wind tunnel and field trials. From the result of these a number of conclusions and recommendations can be drawn:

9.1. The Effectiveness of the Various Chemical Treatments in the Stabilization of Druridge Bay Sand Dunes:

From the results of the laboratory, greenhouse and field trials reported in chapters 5 and 8 and summarised in tables (9.1 - 9.3), the eleven different chemical treatments can be ranked in decreasing order of suitability as follows:

a. Aquapol 1 and possibly Aquapol 2: From the laboratory experiments using concentrations of 0.66% and 0.33%, Aq1 proved to be permeable, it reduced evaporation losses, increased sub-surface temperatures and was not toxic to any of the species used in the germination and growth trials. After the 405 day growth experiments the aggregates formed by Aq1 remained very stable, having the lowest stability index of any of the treatments. In both the water and wind erosion tests, Aq1 treated surfaces remained completely stable, a situation repeated in the field trials in which the surface remained stabilized even when undercut from below. Aq2 which, as the result of late release was only partially tested, behaved in a similar way to Aq1, although it did have an adverse effect on germination rates, this was thought to be due not to toxicity but to the formation of a very resistant surface crust which the emergent seedlings had difficulty penetrating. It is however, the formation this tough, flexible and permeable crust that accounts for the success of the Aquapol treatments. Thus both Aq1 and Aq2 met all the requirements of a stabilizer. Both Aq1 and Aq2 share one problem, namely that of gelating times. Aq1 with a gelating time of 1 minute is especially difficult to apply

Table 9.1: Summary of the Effect of Various Chemical Treatments on the Infiltration Characteristics, Sand Temperature and Evaporation Measurements and the Toxicity Effects in Druridge Bay Dune Sands Compared With the Untreated Samples - Laboratory Tests.

Treats	Conc.*	I.R.	A.I.	H.C.	I.P.	Sand Temperature E. S	E. 5	E. 10	M. S	M. Grass 5	M. Exp. 10	Evaporation	Toxicity Effects
PVA1	0.1%	+	+	+	+								
	0.2%	+	+	+	+	+	+	≃	+	+	≃	−	NT
	0.4%	+	+	+	+	+	+	=	+	+	≃	−	NT
PVA2	0.1%	+	+	+	+								
	0.2%	+	+	+	+	=	+	≃	≃	+	≃	−	NT
	0.4%	+	+	+	+	=	+	≃	+	+	≃	−	NT
PEG3	0.1%	+	+	+	+								
	0.2%	+	+	+	+	=	+	≃	≃	≃	≃	+	NT
	0.4%	+	+	+	+	≃	+	+	≃	≃	≃	+	NT
PEG4	0.1%	+	+	+	+								
	0.2%	+	+	+	+	=	+	≃	≃	+	≃	+	NT
	0.4%	+	+	+	+	≃	+	≃	≃	+	≃	+	NT
V1	0.05 l m^{-2}	−	−	−	−	+	+	≃	≃	+	+	−	NT
	0.10 l m^{-2}	−	−	−	−	+	+	≃	+	+	+	−	NT
V2	0.05 l m^{-2}	−	−	−	−	+	+	≃	≃	+	≃	−	NT
	0.10 l m^{-2}	−	−	−	−	+	+	=	≃	+	≃	−	NT
V3	0.05 l m^{-2}	−	−	−	−	+	+	≃	≃	+	≃	−	NT
	0.10 l m^{-2}	−	−	−	−	+	+	≃	+	+	≃	−	NT
F.E.	0.2 l m^{-2}	−	−	−	−	+	+	+	+	+	≃	−	NT
	0.4 l m^{-2}	−	−	−	−	+	+	+	+	+	≃	−	NT
B.E.	0.5 l m^{-2}	−	−	−	−	+	+	≃	+	+	+	−	NT
	1.0 l m^{-2}	−	−	−	−	+	+	+	+	+	+	−	NT
	1.5 l m^{-2}	−	−	−	−								
Aq1	0.33%	−	−	−	−	+	+	≃	+	+	≃	−	NT
	0.50%	−	−	−	−								
	0.66%	−	−	−	−	+	+	≃	+	+	≃	−	NT
Aq2	200 gm m^{-2}	−	−	−	−								NT
	250 gm m^{-2}	−	−	−	−								NT

* All (%) are on the base of air-dry sand; I.R. is Infiltration Rate; A.I. is Accumulated Infiltration; H.C. is Hydraulic Conductivity; I.P. is Intrinsic Permeability; S is at the surface; 5 and 10 are at 5 cm and 10 cm depths respectively; + is increased; − is decreased; = is equalled; ≃ is ∓ 0.1-0.2°C; NT is not toxic.

Table 9.2: Summary of the Effect of Various Chemical Treatments on the Stability of Sand Aggregates and Withstanding Both Wind and Water Erosion in Druridge Bay Dune Sands - Laboratory Tests.

Treats	Conc.*	Air-Dry Aggregates		Water Stable Aggregates		Wind Erosion			Water
		After Days From Treat.		After Days From Treat.		At Slopes			Erosion
		3 Days	405 Days	3 Days	405 Days	0^o	15^o	30^o	
Control		VW	VW	VW	VW	HE	HE	HE	HE
PVA1	0.2%	VW	VW	VW	VW	NE	NE	NE	HE
	0.4%	W	VW	W	VW	NE	NE	NE	HE
PVA2	0.2%	W	VW	VW	VW	NE	SE	SE	SE
	0.4%	F	VW	VW	VW	NE	SE	SE	SE
PEG3	0.2%	VW	VW	VW	VW	NE	SE	SE	HE
	0.4%	VW	VW	VW	VW	NE	SE	SE	HE
PEG4	0.2%	VW	VW	VW	VW	NE	SE	SE	HE
	0.4%	VW	VW	VW	VW	NE	SE	SE	HE
V1	0.05 l m^{-2}	VW	VW	VW	VW	NE	SE	SE	HE
	0.10 l m^{-2}	F	VW	W	VW	NE	SE	SE	SE
V2	0.05 l m^{-2}	W	VW	VW	VW	NE	SE	SE	SE
	0.10 l m^{-2}	G	VW	VW	VW	NE	NE	NE	SE
V3	0.05 l m^{-2}	VW	VW	VW	VW	NE	NE	NE	SE
	0.10 l m^{-2}	W	VW	VW	VW	NE	NE	NE	SE
F.E.	0.2 l m^{-2}	VW	VW	VW	VW	NE	NE	NE	SE
	0.4 l m^{-2}	W	VW	W	VW	NE	NE	NE	SE
B.E.	0.5 l m^{-2}	W	W	W	W	NE	NE	NE	SE
	1.0 l m^{-2}	G	VG	G	VG	NE	NE	NE	NE
Aq1	0.33%	W	VW	W	VW	NE	NE	NE	SE
	0.66%	E	E	E	E	NE	NE	NE	NE
Aq2	200 gm m^{-2}	G		F		NE	NE	NE	SE
	250 gm m^{-2}	E		VG		NE	NE	NE	NE

* All (%) are on the base of air-dry sand; > 0.5 mm aggregates were used as indicator for the stability ranking of air-dry and water stable aggregates as follows: VW = Very Weak < 20%, W = Weak 20-34%, F = Fair 35-49%, G = Good 50-69%, VG = Very Good 70-85, E = Excellent > 85%; NE = No Erosion; SE = Slightly Eroded; HE = Highly Eroded.

Table 9.3: Summary of the Effect of Various Chemical Treatments on the Infiltration Characteristics, Modulus of Rupture, the Flexibility and the Stability of the Surface Layer in Duridge Bay Sand Dunes - Field Work Tests.

Treats	Conc.*	I.R.	A.I.	MOR	Flexibility	Stability
Control					NF	NS
F.E.	0.2 l m^{-2}	–	–	+	NF	S
	0.4 l m^{-2}	–	–	+	NF	S
B.E.	0.5 l m^{-2}	–	–	+	NF	S
	1.0 l m^{-2}	–	–	+	NF	S
Aq1	0.66%	–	–	+	F	S
	1.00%	–	–	+	F	S

* Aq1 (%) are on the base of air-dry sand; I.R. is Infiltration Rate; A.I. is Accumulated Infiltration; MOR is Modulus of Rupture; Infiltration rate, accumulated infiltration and modulus of rupture are compared with the control as follows: + is increased and – is decreased; F = Flexible; NF = Not Flexible; S = Stable and NS = Not Stable.

and would require specialised equipment. Aq2 which gelates in 20 minutes also restricts the use of sparyers.

b. B.E. 1.0 l m^{-2} followed by B.E. 0.5 l m^{-2} are also effective in stabilizing aeolian sand dunes as they behaved almost identically to Aq1, except for slightly poorer aggregation indices after 3 and 405 days, and in the field did not produce the 'flexible' surface of Aq1.

c. F.E. (0.4 and 0.2 l m^{-2}) treatments could be used as a good alternative to either of the above chemical stabilizers, as both concentrations proved to be permeable, reduced evaporation losses, increased sub-surface temperatures

and was not toxic to any of the species used in the germination and growth experiments. After the 405 day growth experiments, both concentrations appeared to maintain a much more effective stable surface cover when compared to all other treatments except Aq1 0.66% and B.E. (1.0 and 0.5 l m^{-2}). Although stable in the wind erosion tests, F.E. treated surfaces were slightly damaged by water erosion, and hence F.E. is considered not quite as effective as either Aq1 or B.E.

d. The remaining chemical treatments PVA2 (0.2% and 0.4%) and V3 (0.05 and 0.10 l m^{-2}) followed by PVA1 (0.2% and 0.4%); V1 (0.05 and 0.10 l m^{-2}); V2 (0.05 and 0.10 l m^{-2}); PEG3 (0.2% and 0.4%) and PEG4 (0.2% and 0.4%), are not considered to be effective sand dune stabilizers. Although in the various concentrations used they proved permeable, non-toxic and reduced evaporation rates (except PEG3 and PEG4 which increased evaporation rates), they lost their ability to stabilize the surface within two months of the start of the greenhouse growth trials, thus after 405 days the sand showed no evidence of enhanced aggregation. Furthermore, in the water erosion tests all began to lose their effectiveness within the 20 minute duration of the experiment. Because of this lack of long term stability none were carried forward for field trials. Thus whilst these 7 chemicals may be useful as short term conditioners they cannot be consider to be suitable for sand dune stabilization schemes.

9.2 The Effectiveness of the Various Chemical Treatments in the Stabilization of Baiji (Central Iraq) Sand Dunes:

From the results of the laboratory and greenhouse experiments reported in chapter 6 and summarised in table 9.4, Aq1 (0.33% and 0.66%) was the most successful, as it enhanced germination rates of all plant species tested. Following Aq1, PVA2 (0.2%) was the only other treatment that enhanced germination rate,

Table 9.4: Summary of the Effect of Various Chemical Treatments on the Infiltration Characteristics, Sand Temperature and the Toxicity Effects in Baiji Dune Sand Compared With the Untreated Samples - Laboratory Tests.

Treats	Conc.*	I.R.	A.I.	H.C.	I.P.	Sand Temperature			Toxicity Effects
						S	5	10	
PVA2	0.2%	+	+	+	+	≃	≃	≃	NT
	0.4%	+	+	+	+	≃	+	+	NT
F.E.	0.14 l m^{-2}	−	−	−	−				
	0.18 l m^{-2}	−	−	−	−				
	0.2 l m^{-2}	−	−	−	−	+	+	≃	NT
	0.4 l m^{-2}	−−	−−	−−	−−	+	+	+	NT
B.E.	0.3 l m^{-2}	−	−	−	−				
	0.4 l m^{-2}	−	−	−	−				
	0.5 l m^{-2}	−−	−−	−−	−−	+	+	+	NT
	1.0 l m^{-2}	−−	−−	−−	−−	+	+	+	NT
Aq1	0.33%	−	−	−	−	+	+	≃	NT
	0.50%	−	−	−	−				
	0.66%	−−	−−	−−	−−	+	+	+	NT
Aq2	150 gm m^{-2}	−	−	−	−				
	175 gm m^{-2}	−	−	−	−				
	200 gm m^{-2}	−	−	−	−				
	225 gm m^{-2}	−	−	−	−				

* All (%) are on the base of air-dry sand; I.R. is Infiltration Rate; A.I. is Accumulated Infiltration; H.C. is Hydraulic Conductivity; I.P. is Intrinsic Permeability; S is at the surface; 5 and 10 are at 5 cm and 10 cm depths respectively; + is increased; − is decreased; −− is drastically decreased; = is equalled; ≃ is ∓ 0.1-0.2°C; NT is not toxic.

but only on 3 of the 4 species tested. Both B.E. treatments and F.E. treatments caused the greatest reduction in germination success, the higher concentrations of these are especially detrimental. However, all the seeds germination results were less than those of Druridge Bay sands. These were possibly due to: firstly, the hard surface crust made by both F.E. and PVA2 (especially 0.4%), and; secondly, the effect of the three first chemicals (i.e. Aq1; B.E. and F.E.) on the infiltration rate. It is found later that the chemicals Aq1 (0.33% and 0.66%); F.E. (0.2 and 0.4 l m^{-2}) and B.E. (0.5 and 1.0 l m^{-2}) reacted differently with the Baiji sand and, they rendered the samples impermeable or at best drastically reduced the infiltration rate. As a consequence the infiltration rate experiment was repeated using lower concentrations of the chemicals: F.E. 0.14 and 0.18 l m^{-2}; B.E. 0.3 and 0.4 l $m^{-2}$and Aq1 0.33% and 0.50%. An important point related to PVA2 and Aq1 should be mentioned in which both PVA2 concentrations (0.2% and 0.4%) and Aq1 (only 0.33%) only formed a very thin surface crust (about 2 mm thick). Any damage in this thin surface layer will thus expose the loose sand beneath to both wind and water erosion. In the case of the remaining chemicals i.e. Aq1 (0.50% and 0.66%); B.E. (0.3; 0.4; 0.5 and 1.0 l m^{-2}) and F.E. (0.14; 0.18; 0.2 and 0.4 l m^{-2}), a hard layer of about (16 mm thick) had formed at the surface, this will greatly increase the resistance of the sand to erosion.

9.3 Cost Effectiveness of the Treatments:

When costs are considered ranking of Aq1; Aq2 > B.E. > F.E. changes. Bitumen (0.5 and 1.0 l m^{-2}) a by-product of the oil industry would cost respectively £575 and £1150 to treat 1 hectare of sand dunes; F.E. (0.2 and 0.4 l m^{-2}) would cost £860 and £1720 respectively; whilst Aq1 (0.66% and 1.0%) and Aq2 (200 and 250 gm m^{-2}) would cost (£5160 and £7800) and (£6000 and £7500) respectively to treat the same area. Thus on the basis of cost, the treatments now rank B.E. > F.E. > Aq1 and Aq2.

Straight economic cost however has to be balanced against effectiveness and the acceptibility of the treatment. Bitumen for example, produces an unsightly black surface which can stick to clothing etc.. should people come into contact with it. Thus in an area such as Druridge Bay which is open to the public and is also an SSSI, the use of bitumen would almost certainly be environmentally unacceptable whereas colourless Aq1; Aq2 and F.E. would be acceptable. Whilst in central Iraq no such objections might be forthcoming. In obvious public areas however it may be better to use either Ferquatac emulsions or Aquapol emulsions.

9.4 The Importance of Testing Chemicals at each Site:

From section 9.1 and 9.2 it is evident that different concentrations of the chemicals must be used in order to ensure permeability. Thus it is essential that where any chemical mulch is to be used, trials are carried out on the materials to be stabilized so as to ensure that the surface remains permeable. In no circumstances should information obtained from one area be adopted for another, without these permeability tests taking place.

9.5 Soil Conditioners and Soil Stabilizers:

The use of the term soil conditioner/stabilizer as used in the literature is very ambiguous eg. the general definition of soil conditioner as given by Hallsworth (1976) "**soil conditioning**" means "by and large, altering the surface structure in such a way as to give better conditions for plant growth" is considered much too general for the purpose of this research into sand dune stabilization. It is important to differentiate between those chemicals which provide a short term improvement in soil aggregation/structure and those which provide long term surface protection. For the purpose of sand dune stabilization it is essential that any chemical material used is sufficiently stable to last until the plant cover is adequately established to resist/prevent erosion. During the laboratory and green-

house trials, it became rapidly apparent that a number of the chemicals supposedly established in the literature as being suitable for sand dune stabilization were in fact not suitable, these were PVA1; PVA2; PEG3; PEG4; V1; V2 and V3. Thus it is essential that a differentiation is made between **'stabilizers'** which remain effective for a period of at least twelve months and **'general soil conditioners'** which provide only a relatively short period of protection. Thus of the chemicals tested here, only B.E.; F.E.; Aq1 and Aq2 can be considered to be **'stabilizers'.**

9.6 Further Recommendations:

Further work needs to be undertaken into: (a) possibility of using the chemicals in strips/bands etc... for the stabilization of aeolian sand dunes in order to reduce the area treated hence reducing costs. The orientation of these strips/bands will depend probably on one or more of the following: Firstly, wind direction: in order to prevent the surface erosion by wind and therefore the creation of the small wadis, stabilizers must be applied to the surface in which the strips will be perpendicular to the prevailing wind direction. Secondly, sand slope: strips must be perpendicular to the dune slope in order to prevent the natural surface creep from the untreated bands creating narrow "canals" which would make the site much more vulnerable to the wind. Thirdly, aesthetic reasons: the dune sides facing to public transportation and holiday makers etc... should be treated by the colourless stabilizers such as Aquapol and Fequatac emulsions despite their high application costs; whilst, the dunes lee sides could be treated by any chemical stabilizer (eg. bitumen emulsions). (b) the use of the chemical stabilizers: Aq1; Aq2; B.E and F.E. for the stabilization of desertic sand dunes - the laboratory trials need to be extended to the field.

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APPENDICES

Appendix 1: Determination of Goodness of Fit of Equation $Y = at^{a} + b$.

Appendix 2: Statistical Analysis Tables.

Appendix 3: Sand Accumulation (A) and Sand Erosion (E) in (mm) for Druridge Bay Field Site 1.

Table 5.1 : Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Control Samples.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	10.19	10.85	1.04	0.30	10.11	-0.86
4.00	20.15	20.80	1.32	0.60	20.22	0.32
6.00	30.01	30.66	1.49	0.78	30.10	0.27
8.00	39.78	40.43	1.61	0.90	39.83	0.14
10.00	49.40	50.05	1.70	1.00	49.47	0.14
12.00	58.97	59.62	1.78	1.08	58.99	0.03
14.00	68.49	69.14	1.84	1.15	68.47	-0.04
16.00	78.02	78.67	1.90	1.20	77.88	-0.18
18.00	87.40	88.05	1.95	1.26	87.21	-0.22
20.00	96.73	97.38	1.99	1.30	96.57	-0.16
22.00	105.97	106.62	2.03	1.34	105.75	-0.20
25.00	119.67	120.32	2.08	1.40	119.71	0.03
28.00	133.29	133.94	2.13	1.45	133.42	0.10
31.00	146.90	147.55	2.17	1.49	147.06	0.11
35.00	165.08	165.73	2.22	1.54	165.33	0.15
40.00	187.73	188.38	2.28	1.60	187.94	0.11

Table 5.2a: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With PVA1 0.1%*.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	11.06	11.90	1.08	0.30	11.13	0.63
4.00	21.79	22.63	1.36	0.60	21.99	0.91
6.00	32.32	33.16	1.52	0.78	32.45	0.39
8.00	42.67	43.51	1.64	0.90	42.68	0.03
10.00	52.91	53.75	1.73	1.00	52.74	-0.32
12.00	63.06	63.90	1.81	1.08	62.63	-0.69
14.00	72.87	73.71	1.87	1.15	72.43	-0.61
16.00	82.49	83.33	1.92	1.20	82.13	-0.44
18.00	92.06	92.90	1.97	1.26	91.72	-0.38
20.00	101.54	102.38	2.01	1.30	101.31	-0.23
22.00	110.97	111.81	2.05	1.34	110.69	-0.25
25.00	124.96	125.81	2.10	1.40	124.92	-0.04
28.00	138.77	139.61	2.15	1.45	138.85	0.06
31.00	152.57	153.41	2.19	1.49	152.66	0.06
35.00	170.85	171.69	2.24	1.54	171.13	0.17
40.00	193.65	194.49	2.29	1.60	193.90	0.13

* PVA1 (%) is on the base of air-dry sand.

Table 5.2b: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With PVA1 0.2%*.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	12.70	13.76	1.14	0.30	12.68	-0.18
4.00	24.68	25.74	1.41	0.60	24.88	0.82
6.00	36.32	37.38	1.57	0.78	36.56	0.66
8.00	47.76	48.83	1.69	0.90	47.92	0.33
10.00	59.02	60.09	1.78	1.00	59.05	0.05
12.00	70.18	71.24	1.85	1.08	69.96	-0.31
14.00	81.19	82.26	1.92	1.15	80.76	-0.54
16.00	92.06	93.13	1.97	1.20	91.42	-0.70
18.00	102.79	103.86	2.02	1.26	101.93	-0.83
20.00	113.32	114.39	2.06	1.30	112.44	-0.78
22.00	123.62	124.68	2.10	1.34	122.70	-0.74
25.00	138.43	139.50	2.15	1.40	138.24	-0.14
28.00	153.25	154.31	2.19	1.45	153.42	0.12
31.00	167.97	169.03	2.23	1.49	168.46	0.30
35.00	187.11	188.18	2.28	1.54	188.54	0.76
40.00	211.06	212.13	2.33	1.60	213.24	1.03

* PVA1 (%) is on the base of air-dry sand.

Table 5.2c: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With PVA1 0.4%*.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	13.28	15.07	1.18	0.30	13.13	-1.12
4.00	26.07	27.87	1.45	0.60	26.30	0.88
6.00	38.58	40.37	1.61	0.78	38.88	0.79
8.00	50.84	52.64	1.72	0.90	51.10	0.51
10.00	63.01	64.81	1.81	1.00	63.07	0.09
12.00	74.89	76.69	1.89	1.08	74.79	-0.14
14.00	86.63	88.42	1.95	1.15	86.37	-0.30
16.00	98.33	100.11	2.00	1.20	97.80	-0.52
18.00	109.67	111.46	2.05	1.26	109.08	-0.54
20.00	120.73	122.53	2.09	1.30	120.33	-0.33
22.00	131.70	133.49	2.13	1.34	131.33	-0.28
25.00	147.86	149.65	2.18	1.40	147.96	0.07
28.00	164.02	165.82	2.22	1.45	164.21	0.11
31.00	179.89	181.69	2.26	1.49	180.29	0.22
35.00	200.87	202.66	2.31	1.54	201.76	0.44
40.00	227.03	228.83	2.36	1.60	228.15	0.49

* PVA1 (%) is on the base of air-dry sand.

Table 5.3a: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With PVA2 0.1%*.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	12.51	14.52	1.16	0.30	12.56	0.40
4.00	24.34	26.36	1.42	0.60	24.78	1.82
6.00	35.88	37.90	1.59	0.78	36.25	1.03
8.00	47.14	49.16	1.69	0.90	47.27	0.28
10.00	58.15	60.17	1.78	1.00	57.96	-0.33
12.00	68.88	70.90	1.85	1.08	68.36	-0.75
14.00	79.27	81.29	1.91	1.15	78.58	-0.87
16.00	89.32	91.34	1.96	1.20	88.62	-0.79
18.00	99.04	101.06	2.01	1.26	98.48	-0.57
20.00	108.51	110.53	2.04	1.30	108.28	-0.21
22.00	117.89	119.91	2.08	1.34	117.83	-0.06
25.00	131.89	133.91	2.13	1.40	132.21	0.24
28.00	145.84	147.86	2.17	1.45	146.20	0.25
31.00	159.69	161.71	2.21	1.49	160.01	0.20
35.00	177.92	179.94	2.26	1.54	178.36	0.24
40.00	200.58	202.60	2.31	1.60	200.82	0.12

* PVA2 (%) is on the base of air-dry sand.

Table 5.3b: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With PVA2 0.2%*.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	13.04	15.16	1.18	0.30	13.04	0.06
4.00	25.59	27.71	1.44	0.60	25.98	1.53
6.00	37.95	40.08	1.60	0.78	38.19	0.62
8.00	49.83	51.96	1.72	0.90	49.96	0.25
10.00	61.52	63.64	1.80	1.00	61.41	-0.18
12.00	72.97	75.09	1.88	1.08	72.57	-0.54
14.00	84.18	86.30	1.94	1.15	83.57	-0.72
16.00	95.14	97.27	1.99	1.20	94.38	-0.80
18.00	105.87	107.99	2.03	1.26	105.02	-0.81
20.00	116.35	118.48	2.07	1.30	115.61	-0.64
22.00	126.70	128.82	2.11	1.34	125.93	-0.61
25.00	141.75	143.88	2.16	1.40	141.50	-0.18
28.00	156.52	158.64	2.20	1.45	156.67	0.10
31.00	171.33	173.46	2.24	1.49	171.65	0.19
35.00	190.67	192.79	2.29	1.54	191.59	0.48
40.00	214.62	216.75	2.34	1.60	216.04	0.66

* PVA2 (%) is on the base of air-dry sand.

Table 5.3c: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With PVA2 0.4%*.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	13.37	15.54	1.19	0.30	13.40	0.18
4.00	26.17	28.34	1.45	0.60	26.70	2.02
6.00	38.72	40.89	1.61	0.78	39.25	1.36
8.00	51.13	53.30	1.73	0.90	51.36	0.44
10.00	63.25	65.42	1.82	1.00	63.14	-0.17
12.00	75.13	77.30	1.89	1.08	74.64	-0.66
14.00	86.68	88.85	1.95	1.15	85.95	-0.84
16.00	98.08	100.25	2.00	1.20	97.09	-1.01
18.00	109.00	111.17	2.05	1.26	108.04	-0.88
20.00	119.67	121.84	2.09	1.30	118.94	-0.61
22.00	130.21	132.38	2.12	1.34	129.57	-0.49
25.00	145.55	147.72	2.17	1.40	145.61	0.04
28.00	160.22	162.39	2.21	1.45	161.00	0.49
31.00	175.28	177.45	2.25	1.49	176.68	0.80
35.00	195.72	197.89	2.30	1.54	197.22	0.77
40.00	220.68	222.85	2.35	1.60	222.42	0.79

* PVA2 (%) is on the base of air-dry sand.

Table 5.4a: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With PEG3 0.1%*.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	11.74	13.23	1.12	0.30	11.86	1.02
4.00	23.09	24.59	1.39	0.60	23.40	1.36
6.00	34.10	35.60	1.55	0.78	34.35	0.72
8.00	44.88	46.37	1.67	0.90	44.93	0.13
10.00	55.46	56.96	1.76	1.00	55.26	-0.36
12.00	65.85	67.35	1.83	1.08	65.34	-0.77
14.00	75.95	77.45	1.89	1.15	75.28	-0.88
16.00	85.81	87.31	1.94	1.20	85.08	-0.85
18.00	95.43	96.93	1.99	1.26	94.72	-0.75
20.00	104.91	106.40	2.03	1.30	104.33	-0.55
22.00	114.19	115.69	2.06	1.34	113.70	-0.43
25.00	127.80	129.30	2.11	1.40	127.86	0.05
28.00	141.32	142.82	2.16	1.45	141.67	0.25
31.00	154.83	156.33	2.19	1.49	155.33	0.32
35.00	172.78	174.27	2.24	1.54	173.51	0.43
40.00	195.05	196.54	2.29	1.60	195.84	0.41

* PEG3 (%) is on the base of air-dry sand.

Table 5.4b: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With PEG3 0.2%*.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	12.41	14.64	1.17	0.30	12.31	-0.80
4.00	24.39	26.61	1.43	0.60	24.75	1.48
6.00	36.12	38.35	1.58	0.78	36.50	1.04
8.00	47.62	49.85	1.70	0.90	47.83	0.45
10.00	58.87	61.10	1.79	1.00	58.87	-0.01
12.00	69.89	72.12	1.86	1.08	69.63	-0.37
14.00	80.57	82.80	1.92	1.15	80.23	-0.42
16.00	91.01	93.23	1.97	1.20	90.66	-0.38
18.00	101.25	103.48	2.02	1.26	100.92	-0.33
20.00	111.26	113.48	2.06	1.30	111.14	-0.10
22.00	121.12	123.34	2.09	1.34	121.10	-0.01
25.00	135.74	137.97	2.14	1.40	136.14	0.29
28.00	150.27	152.49	2.18	1.45	150.79	0.35
31.00	164.79	167.02	2.22	1.49	165.26	0.28
35.00	183.93	186.16	2.27	1.54	184.52	0.32
40.00	207.79	210.02	2.32	1.60	208.14	0.17

* PEG3 (%) is on the base of air-dry sand.

Table 5.4c: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With PEG3 0.4%*.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	13.37	16.20	1.21	0.30	13.43	0.46
4.00	26.17	29.00	1.46	0.60	26.65	1.84
6.00	38.53	41.36	1.62	0.78	38.91	0.98
8.00	50.60	53.43	1.73	0.90	50.60	-0.01
10.00	62.29	65.12	1.81	1.00	61.88	-0.65
12.00	73.45	76.28	1.88	1.08	72.81	-0.87
14.00	84.27	87.10	1.94	1.15	83.52	-0.89
16.00	94.76	97.59	1.99	1.20	94.00	-0.80
18.00	104.91	107.74	2.03	1.26	104.27	-0.61
20.00	114.82	117.65	2.07	1.30	114.46	-0.31
22.00	124.48	127.31	2.11	1.34	124.35	-0.10
25.00	138.87	141.70	2.15	1.40	139.23	0.27
28.00	153.25	156.08	2.19	1.45	153.67	0.28
31.00	167.53	170.36	2.23	1.49	167.89	0.22
35.00	186.58	189.41	2.28	1.54	186.73	0.08
40.00	210.34	213.17	2.33	1.60	209.75	-0.28

* PEG3 (%) is on the base of air-dry sand.

Table 5.5a: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With PEG4 0.1%*.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	11.83	12.38	1.09	0.30	11.81	-0.23
4.00	23.14	23.69	1.37	0.60	23.20	0.29
6.00	34.20	34.75	1.54	0.78	34.26	0.17
8.00	45.07	45.62	1.66	0.90	45.11	0.09
10.00	55.80	56.35	1.75	1.00	55.82	0.03
12.00	66.28	66.83	1.83	1.08	66.36	0.12
14.00	76.86	77.41	1.89	1.15	76.84	-0.03
16.00	87.30	87.85	1.94	1.20	87.23	-0.09
18.00	97.55	98.10	1.99	1.26	97.51	-0.04
20.00	107.70	108.25	2.03	1.30	107.81	0.10
22.00	117.80	118.35	2.07	1.34	117.89	0.08
25.00	132.90	133.45	2.13	1.40	133.21	0.23
28.00	148.00	148.55	2.17	1.45	148.22	0.15
31.00	163.01	163.56	2.21	1.49	163.00	-0.01
35.00	182.97	183.52	2.26	1.54	183.10	0.07
40.00	207.84	208.39	2.32	1.60	207.75	-0.04

* PEG4 (%) is on the base of air-dry sand.

Table 5.5b: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With PEG4 0.2%*.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	11.98	12.31	1.09	0.30	12.16	1.57
4.00	23.52	23.85	1.37	0.60	23.69	0.73
6.00	34.83	35.15	1.54	0.77	34.87	0.15
8.00	45.94	46.26	1.66	0.90	45.85	-0.18
10.00	56.90	57.23	1.75	1.00	56.68	-0.39
12.00	67.72	68.05	1.83	1.07	67.35	-0.55
14.00	78.40	78.73	1.89	1.14	77.95	-0.58
16.00	88.93	89.27	1.95	1.20	88.45	-0.54
18.00	99.32	99.66	1.99	1.25	98.85	-0.47
20.00	109.57	109.90	2.04	1.30	109.27	-0.27
22.00	119.67	120.00	2.07	1.34	119.48	-0.16
25.00	134.77	135.10	2.13	1.39	134.97	0.15
28.00	149.78	150.11	2.17	1.44	150.16	0.25
31.00	164.79	165.12	2.21	1.49	165.24	0.28
35.00	184.70	185.03	2.26	1.54	185.44	0.40
40.00	209.52	209.85	2.32	1.60	210.37	0.41

* PEG4 (%) is on the base of air-dry sand.

Table 5.5c: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With PEG4 0.4%*.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	12.69	13.71	1.14	0.30	12.68	-0.12
4.00	25.06	26.07	1.42	0.60	25.19	0.53
6.00	37.18	38.19	1.58	0.78	37.28	0.28
8.00	49.11	50.12	1.70	0.90	49.12	0.03
10.00	60.84	61.86	1.79	1.00	60.78	-0.10
12.00	72.43	73.45	1.87	1.08	72.25	-0.25
14.00	83.88	84.90	1.93	1.15	83.63	-0.30
16.00	95.19	96.20	1.98	1.20	94.91	-0.29
18.00	106.34	107.36	2.03	1.26	106.05	-0.28
20.00	117.36	118.38	2.07	1.30	117.21	-0.13
22.00	128.28	129.30	2.11	1.34	128.13	-0.11
25.00	144.54	145.55	2.16	1.40	144.70	0.11
28.00	160.79	161.81	2.21	1.45	160.93	0.09
31.00	177.00	178.02	2.25	1.49	177.04	0.02
35.00	198.50	199.52	2.30	1.54	198.59	0.04
40.00	225.34	226.36	2.36	1.60	225.17	-0.08

* PEG4 (%) is on the base of air-dry sand.

Table 5.6a: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With B.E. 0.5 l m^{-2}.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	9.14	9.81	0.99	0.30	9.01	-1.46
4.00	17.89	18.56	1.27	0.60	17.93	0.23
6.00	26.45	27.12	1.43	0.78	26.60	0.53
8.00	34.96	35.64	1.55	0.90	35.10	0.37
10.00	43.38	44.05	1.64	1.00	43.48	0.23
12.00	51.70	52.38	1.72	1.08	51.75	0.08
14.00	59.98	60.65	1.78	1.15	59.96	-0.04
16.00	68.15	68.83	1.84	1.20	68.09	-0.10
18.00	76.19	76.86	1.89	1.26	76.25	0.07
20.00	84.17	84.84	1.93	1.30	84.21	0.05
22.00	92.16	92.83	1.97	1.34	92.12	-0.05
25.00	104.04	104.71	2.02	1.40	104.12	0.07
28.00	115.87	116.54	2.07	1.45	115.88	0.01
31.00	127.61	128.28	2.11	1.49	127.56	-0.04
35.00	143.19	143.87	2.16	1.54	143.20	0.01
40.00	162.62	163.30	2.21	1.60	162.51	-0.07

Table 5.6b: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With B.E. 1.0 l m^{-2}.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	4.76	5.23	0.72	0.30	4.65	-2.27
4.00	9.04	9.51	0.98	0.60	9.10	0.66
6.00	13.18	13.64	1.14	0.78	13.33	1.12
8.00	17.26	17.73	1.25	0.90	17.42	0.86
10.00	21.30	21.77	1.34	1.00	21.41	0.47
12.00	25.30	25.77	1.41	1.08	25.31	0.04
14.00	29.14	29.61	1.47	1.15	29.16	0.03
16.00	32.94	33.41	1.52	1.20	32.95	0.01
18.00	36.74	37.21	1.57	1.26	36.69	-0.17
20.00	40.50	40.96	1.61	1.30	40.41	-0.22
22.00	44.15	44.62	1.65	1.34	44.04	-0.25
25.00	49.49	49.96	1.70	1.40	49.53	0.08
28.00	54.83	55.30	1.74	1.45	54.89	0.10
31.00	59.98	60.45	1.78	1.49	60.19	0.35
35.00	66.76	67.23	1.83	1.54	67.25	0.72
40.00	75.23	75.70	1.88	1.60	75.92	0.91

Table 5.6c: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With B.E. 1.5 l m^{-2}.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	2.21	2.05	0.31	0.30	2.30	4.02
4.00	4.23	4.07	0.61	0.60	4.24	0.38
6.00	6.15	5.99	0.78	0.78	6.12	-0.46
8.00	8.03	7.87	0.90	0.90	7.96	-0.80
10.00	9.81	9.81	0.99	1.00	9.77	-0.34
12.00	11.59	11.42	1.06	1.08	11.56	-0.28
14.00	13.37	13.20	1.12	1.15	13.32	-0.34
16.00	15.10	14.94	1.17	1.20	15.07	-0.19
18.00	16.78	16.62	1.22	1.26	16.80	0.10
20.00	18.47	18.30	1.26	1.30	18.53	0.35
22.00	20.15	19.99	1.30	1.34	20.22	0.36
25.00	22.70	22.54	1.35	1.40	22.79	0.41
28.00	25.25	25.09	1.40	1.45	25.31	0.23
31.00	27.80	27.63	1.44	1.49	27.80	0.02
35.00	31.16	31.00	1.49	1.54	31.14	-0.08
40.00	35.40	35.23	1.55	1.60	35.26	-0.40

Table 5.7a: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With F.E. 0.2 l m^{-2}.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	3.17	3.17	0.50	0.30	3.21	1.39
4.00	6.15	6.15	0.79	0.60	6.20	0.81
6.00	9.09	9.08	0.96	0.78	9.11	0.25
8.00	11.97	11.97	1.08	0.90	11.97	-0.04
10.00	14.86	14.86	1.17	1.00	14.79	-0.46
12.00	17.74	17.74	1.25	1.08	17.57	-0.96
14.00	20.49	20.48	1.31	1.15	20.34	-0.71
16.00	23.23	23.22	1.37	1.20	23.09	-0.61
18.00	25.92	25.92	1.41	1.26	25.81	-0.45
20.00	28.62	28.61	1.46	1.30	28.53	-0.29
22.00	31.31	31.31	1.50	1.34	31.20	-0.34
25.00	35.30	35.30	1.55	1.40	35.26	-0.11
28.00	39.25	39.24	1.59	1.45	39.24	-0.01
31.00	43.14	43.14	1.64	1.49	43.20	0.13
35.00	48.29	48.28	1.68	1.54	48.50	0.43
40.00	54.73	54.73	1.74	1.60	55.04	0.56

Table 5.7b: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With F.E. 0.4 l m^{-2}.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	3.27	3.30	0.52	0.30	3.27	-0.03
4.00	6.15	6.19	0.79	0.60	6.19	0.55
6.00	8.94	8.98	0.95	0.78	8.98	0.40
8.00	11.68	11.72	1.07	0.90	11.69	0.07
10.00	14.38	14.41	1.16	1.00	14.35	-0.20
12.00	16.97	17.01	1.23	1.08	16.95	-0.14
14.00	19.52	19.56	1.29	1.15	19.52	-0.01
16.00	22.03	22.06	1.34	1.20	22.06	0.17
18.00	24.48	24.51	1.39	1.26	24.57	0.37
20.00	26.93	26.97	1.43	1.30	27.07	0.51
22.00	29.38	29.42	1.47	1.34	29.51	0.44
25.00	33.09	33.12	1.52	1.40	33.21	0.36
28.00	36.74	36.78	1.57	1.45	36.82	0.21
31.00	40.40	40.44	1.61	1.49	40.40	-0.01
35.00	45.26	45.29	1.66	1.54	45.17	-0.20
40.00	51.32	51.35	1.71	1.60	51.04	-0.55

Table 5.8a: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With V1 0.05 l m^{-2}.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2..00	2.89	2.75	0.44	0.30	2.93	1.59
4.00	5.53	5.40	0.73	0.60	5.57	0.62
6.00	8.18	8.04	0.91	0.78	8.14	-0.44
8.00	10.73	10.59	1.03	0.90	10.68	-0.40
10.00	13.23	13.09	1.12	1.00	13.20	-0.21
12.00	15.73	15.59	1.19	1.08	15.69	-0.28
14.00	18.23	18.09	1.26	1.15	18.16	-0.37
16.00	20.68	20.55	1.31	1.20	20.62	-0.30
18.00	23.14	23.00	1.36	1.26	23.06	-0.32
20.00	25.54	25.40	1.41	1.30	25.51	-0.13
22.00	27.95	27.81	1.44	1.34	27.91	-0.13
25.00	31.55	31.42	1.50	1.40	31.56	0.03
28.00	35.11	34.98	1.54	1.45	35.15	0.11
31.00	38.67	38.54	1.59	1.49	38.72	0.12
35.00	43.39	43.25	1.64	1.54	43.50	0.27
40.00	49.26	49.12	1.69	1.60	49.42	0.34

Table 5.8b: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With V1 0.10 l m^{-2}.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	2.45	2.08	0.32	0.30	2.51	2.20
4.00	4.47	4.10	0.61	0.60	4.45	-0.63
6.00	6.44	6.07	0.78	0.78	6.32	-2.02
8.00	8.22	7.85	0.90	0.90	8.14	-0.99
10.00	9.95	9.59	0.98	1.00	9.94	-0.14
12.00	11.68	11.32	1.05	1.08	11.71	0.20
14.00	13.42	13.05	1.12	1.15	13.47	0.34
16.00	15.15	14.78	1.17	1.20	15.20	0.32
18.00	16.88	16.51	1.22	1.26	16.92	0.20
20.00	18.61	18.24	1.26	1.30	18.63	0.09
22.00	20.29	19.92	1.30	1.34	20.31	0.07
25.00	22.84	22.47	1.35	1.40	22.86	0.04
28.00	25.39	25.02	1.40	1.45	25.35	-0.18
31.00	27.89	27.52	1.44	1.49	27.82	-0.26
35.00	31.26	30.89	1.49	1.54	31.13	-0.42
40.00	35.40	35.03	1.54	1.60	35.21	-0.54

Table 5.9a: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With V2 0.05 l m^{-2}.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	3.36	3.38	0.53	0.30	3.40	1.25
4.00	6.44	6.46	0.81	0.60	6.47	0.43
6.00	9.38	9.40	0.97	0.78	9.41	0.33
8.00	12.26	12.28	1.09	0.90	12.27	0.06
10.00	15.15	15.17	1.18	1.00	15.08	-0.47
12.00	17.89	17.91	1.25	1.08	17.83	-0.32
14.00	20.63	20.65	1.32	1.15	20.56	-0.36
16.00	23.37	23.39	1.37	1.20	23.25	-0.52
18.00	26.07	26.09	1.42	1.26	25.91	-0.60
20.00	28.66	28.68	1.46	1.30	28.57	-0.34
22.00	31.21	31.23	1.50	1.34	31.16	-0.16
25.00	35.11	35.13	1.55	1.40	35.10	-0.04
28.00	38.86	38.88	1.59	1.45	38.94	0.21
31.00	42.61	42.63	1.63	1.49	42.75	0.33
35.00	47.61	47.63	1.68	1.54	47.84	0.48
40.00	53.87	53.89	1.73	1.60	54.11	0.44

Table 5.9b: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With V2 0.10 l m^{-2}.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	2.93	2.84	0.45	0.30	3.01	2.42
4.00	5.58	5.48	0.74	0.60	5.60	0.36
6.00	8.18	8.08	0.91	0.78	8.09	-1.08
8.00	10.58	10.48	1.02	0.90	10.51	-0.64
10.00	12.94	12.84	1.11	1.00	12.89	-0.36
12.00	15.30	15.20	1.18	1.08	15.23	-0.46
14.00	17.56	17.46	1.24	1.15	17.54	-0.11
16.00	19.82	19.72	1.30	1.20	19.82	0.01
18.00	22.08	21.98	1.34	1.26	22.07	-0.04
20.00	24.29	24.19	1.38	1.30	24.32	0.13
22.00	26.50	26.40	1.42	1.34	26.52	0.07
25.00	29.77	29.68	1.47	1.40	29.85	0.27
28.00	33.05	32.95	1.52	1.45	33.11	0.20
31.00	36.32	36.22	1.56	1.49	36.34	0.07
35.00	40.64	40.54	1.61	1.54	40.65	0.02
40.00	46.03	45.93	1.66	1.60	45.96	-0.16

Table 5.10a: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With V3 0.05 l m^{-2}.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	5.44	5.55	0.74	0.30	5.41	-0.50
4.00	10.53	10.65	1.03	0.60	10.56	0.27
6.00	15.54	15.65	1.20	0.78	15.58	0.30
8.00	20.49	20.61	1.31	0.90	20.53	0.17
10.00	25.40	25.51	1.41	1.00	25.41	0.06
12.00	30.26	30.37	1.48	1.08	30.23	-0.08
14.00	35.07	35.18	1.55	1.15	35.02	-0.11
16.00	39.83	39.94	1.60	1.20	39.78	-0.10
18.00	44.54	44.66	1.65	1.26	44.50	-0.09
20.00	49.21	49.32	1.69	1.30	49.23	0.05
22.00	53.87	53.99	1.73	1.34	53.86	-0.01
25.00	60.80	60.92	1.79	1.40	60.90	0.18
28.00	67.73	67.84	1.83	1.45	67.82	0.14
31.00	74.65	74.77	1.87	1.49	74.69	0.05
35.00	83.84	83.94	1.92	1.54	83.90	0.07
40.00	95.29	95.40	1.98	1.60	95.27	-0.01

Table 5.10b: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With V3 0.10 l m^{-2}.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	3.60	3.60	0.56	0.30	3.63	0.58
4.00	7.02	7.01	0.85	0.60	7.00	-0.38
6.00	10.29	10.28	1.01	0.78	10.27	-0.20
8.00	13.56	13.55	1.13	0.90	13.50	-0.49
10.00	16.69	16.68	1.22	1.00	16.68	-0.06
12.00	19.81	19.80	1.30	1.08	19.82	0.03
14.00	22.94	22.93	1.36	1.15	22.95	0.01
16.00	26.07	26.06	1.42	1.20	26.05	-0.09
18.00	29.14	29.14	1.46	1.26	29.12	-0.11
20.00	32.17	32.17	1.52	1.30	32.19	0.05
22.00	35.20	35.20	1.55	1.34	35.21	0.00
25.00	39.73	39.72	1.60	1.40	39.79	0.15
28.00	44.25	44.24	1.65	1.45	44.29	0.08
31.00	48.77	48.76	1.69	1.49	48.76	-0.03
35.00	54.78	54.77	1.74	1.54	54.74	-0.08
40.00	62.24	62.23	1.79	1.60	62.14	-0.17

Table 5.11a: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With Aq1 0.33%*.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	6.49	6.70	0.83	0.30	6.45	-0.71
4.00	12.50	12.71	1.10	0.60	12.52	0.11
6.00	18.37	18.58	1.27	0.78	18.39	0.06
8.00	24.09	24.30	1.39	0.90	24.13	0.12
10.00	29.77	29.98	1.48	1.00	29.78	0.02
12.00	35.40	35.61	1.55	1.08	35.34	-0.17
14.00	40.93	41.14	1.61	1.15	40.86	-0.18
16.00	46.32	46.53	1.67	1.20	46.32	0.00
18.00	51.70	51.91	1.72	1.26	51.72	0.02
20.00	57.09	57.30	1.76	1.30	57.13	0.05
22.00	62.43	62.64	1.80	1.34	62.42	-0.03
25.00	70.41	70.62	1.85	1.40	70.44	0.03
28.00	78.40	78.61	1.90	1.45	78.30	-0.13
31.00	86.34	86.55	1.94	1.49	86.10	-0.27
35.00	96.87	97.08	1.99	1.54	96.54	-0.35
40.00	110.05	110.26	2.04	1.60	109.40	-0.59

* Aq1 (%) is on the base of air-dry sand.

Table 5.11b: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With Aq1 0.50%*.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	5.14	5.30	0.72	0.30	5.15	0.02
4.00	9.90	10.06	1.00	0.60	9.86	-0.47
6.00	14.43	14.58	1.16	0.78	14.38	-0.38
8.00	18.80	18.96	1.28	0.90	18.77	-0.21
10.00	23.04	23.19	1.37	1.00	23.07	0.15
12.00	27.17	27.33	1.44	1.08	27.30	0.44
14.00	31.26	31.41	1.50	1.15	31.47	0.66
16.00	35.35	35.50	1.55	1.20	35.60	0.69
18.00	39.39	39.54	1.60	1.26	39.67	0.69
20.00	43.43	43.58	1.64	1.30	43.73	0.69
22.00	47.47	47.62	1.68	1.34	47.71	0.48
25.00	53.53	53.68	1.73	1.40	53.72	0.34
28.00	59.54	59.70	1.78	1.45	59.60	0.08
31.00	65.56	65.71	1.82	1.49	65.42	-0.21
35.00	73.59	73.74	1.87	1.54	73.20	-0.54
40.00	83.59	83.75	1.92	1.60	82.76	-1.00

* Aq1 (%) is on the base of air-dry sand.

Table 5.11c: Determination of Goodness of Fit of Equation $Y = at^{a} + b$ in the Sand Samples Treated With Aq1 0.66%*.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	4.95	4.78	0.68	0.30	5.00	0.97
4.00	9.47	9.30	0.97	0.60	9.42	-0.50
6.00	13.75	13.58	1.13	0.78	13.71	-0.32
8.00	17.94	17.77	1.25	0.90	17.91	-0.17
10.00	22.03	21.86	1.34	1.00	22.04	0.07
12.00	26.11	25.95	1.41	1.08	26.11	-0.01
14.00	30.11	29.94	1.48	1.15	30.15	0.15
16.00	34.10	33.93	1.53	1.20	34.15	0.16
18.00	38.09	37.92	1.58	1.26	38.11	0.06
20.00	41.99	41.82	1.62	1.30	42.08	0.21
22.00	45.88	45.71	1.66	1.34	45.96	0.16
25.00	51.70	51.54	1.71	1.40	51.84	0.27
28.00	57.52	57.36	1.76	1.45	57.61	0.16
31.00	63.34	63.18	1.80	1.49	63.34	-0.01
35.00	71.09	70.92	1.85	1.54	71.00	-0.12
40.00	80.71	80.54	1.91	1.60	80.46	-0.31

* Aq1 (%) is on the base of air-dry sand.

Table 5.12a: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With Aq2 200 gm m^{-2}.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	5.41	5.67	0.75	0.30	5.67	4.85
4.00	10.42	10.68	1.03	0.60	10.91	4.72
6.00	15.35	15.61	1.19	0.78	15.96	3.98
8.00	20.18	20.44	1.31	0.90	20.83	3.22
10.00	25.00	25.26	1.40	1.00	25.63	2.50
12.00	29.77	30.03	1.48	1.08	30.29	1.75
14.00	34.45	34.71	1.54	1.15	34.98	1.56
16.00	39.02	39.28	1.59	1.20	39.55	1.37
18.00	43.59	43.85	1.64	1.26	44.10	1.18
20.00	48.16	48.42	1.69	1.30	48.61	0.93
22.00	52.73	52.99	1.72	1.34	52.95	0.42
25.00	59.49	59.75	1.78	1.40	59.72	0.39
28.00	66.26	66.52	1.82	1.45	66.17	-0.22
31.00	72.96	73.22	1.87	1.49	72.69	-0.37
35.00	81.88	82.14	1.92	1.54	81.21	-0.81
40.00	93.05	93.31	1.97	1.60	91.79	-1.36

Table 5.12b: Determination of Goodness of Fit of Equation $Y = at^{\alpha} + b$ in the Sand Samples Treated With Aq2 250 gm m^{-2}.

t (min)	y observed (cm)	y - b	log (y - b)	log t	y calculated (cm)	Deviation (%)
2.00	2.91	2.87	0.46	0.30	2.93	0.58
4.00	5.61	5.57	0.75	0.60	5.58	-0.50
6.00	8.17	8.13	0.91	0.78	8.15	-0.29
8.00	10.68	10.64	1.03	0.90	10.65	-0.25
10.00	13.15	13.11	1.12	1.00	13.13	-0.17
12.00	15.57	15.53	1.19	1.08	15.56	-0.06
14.00	17.96	17.92	1.25	1.15	17.98	0.13
16.00	20.35	20.31	1.31	1.20	20.36	0.05
18.00	22.74	22.70	1.36	1.26	22.74	-0.02
20.00	25.07	25.03	1.40	1.30	25.10	0.11
22.00	27.41	27.37	1.44	1.34	27.45	0.15
25.00	30.89	30.85	1.49	1.40	30.94	0.16
28.00	34.38	34.34	1.54	1.45	34.39	0.04
31.00	37.87	37.83	1.58	1.49	37.88	0.03
35.00	42.51	42.47	1.63	1.54	42.40	-0.26
40.00	48.27	48.23	1.68	1.60	48.12	-0.31

(Appendix 2)

Table 5.13: Statistical Analysis of the Air-Dry Sand Aggregates Percentages > 0.5 mm in Diameter (3 Days After Treatment Samples).

ROW	C1	C2	C3	C4	C5	C6	C7	C8	C9
1	17.59	29.88	25.52	42.97	0.76	0.96	0.31	0.71	11.22
2	14.65	36.02	27.49	46.01	0.56	0.97	0.43	0.80	12.85

ROW	C10	C11	C12	C13	C14	C15	C16	C17	C18
1	51.64	19.07	64.98	10.52	25.84	12.63	26.34	28.36	72.77
2	42.25	24.83	62.23	9.44	25.24	14.10	26.50	26.14	59.41

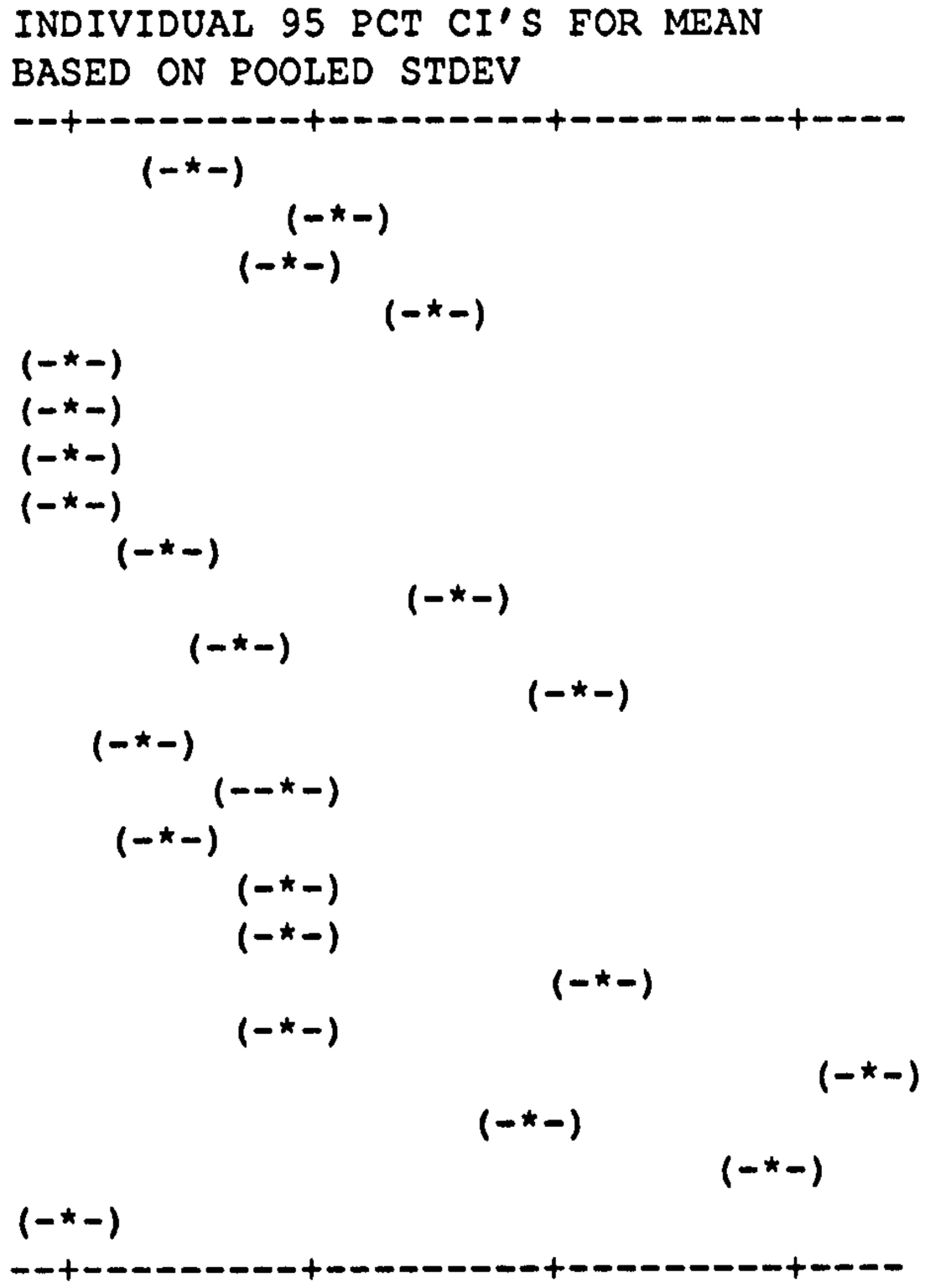
ROW	C19	C20	C21	C22	C23
1	26.90	99.23	57.48	98.53	0.26
2	26.33	97.34	54.80	78.05	0.32

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	22	34624.5	1573.8	89.52**
ERROR	23	404.4	17.6	
TOTAL	45	35028.9		

LEVEL	N	MEAN	STDEV
C1	2	16.12	2.08
C2	2	32.95	4.34
C3	2	26.50	1.39
C4	2	44.49	2.15
C5	2	0.66	0.14
C6	2	0.96	0.01
C7	2	0.37	0.08
C8	2	0.75	0.06
C9	2	12.03	1.15
C10	2	46.94	6.64
C11	2	21.95	4.07
C12	2	63.60	1.94
C13	2	9.98	0.76
C14	2	25.54	0.42
C15	2	13.36	1.04
C16	2	26.42	0.11
C17	2	27.25	1.57
C18	2	66.09	9.45
C19	2	26.61	0.40
C20	2	98.28	1.34
C21	2	56.14	1.90
C22	2	88.29	14.48
C23	2	0.29	0.04

POOLED STDEV = 4.19



* C1-C23 are respectively, PVA1 (0.2%), PVA1 (0.4%), PVA2 (0.2%), PVA2 (0.4%), PEG3 (0.2%), PEG3 (0.4%), PEG4 (0.2%), PEG4 (0.4%), V1 (0.05 l m-2), V1 (0.10 l m-2), V2 (0.05 l m-2), V2 (0.10 l m-2), V3 (0.05 l m-2), V3 (0.10 l m-2), F.E. (0.2 l m-2), F.E. (0.4 l m-2), B.E. (0.5 l m-2), B.E. (1.0 l m-2), Aq1 (0.33%), Aq1 (0.66%), Aq2 (200 gm m-2), Aq2 (250 gm m-2), and Control.
* The pooled, i.e. combined estimate of error is based on the assumption that error for (within) each treatment is the same (in the population).

Table 5.14: Statistical Analysis of the Water Stable Sand Aggregates Percentages > 0.5 mm in Diameter (3 Days After Treatment Samples).

ROW	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
1	8.15	25.81	7.50	10.68	0.39	0.46	0.17	0.38	6.86	24.82
2	12.66	20.35	7.82	12.27	0.26	0.51	0.29	0.32	6.97	21.39

ROW	C11	C12	C13	C14	C15	C16	C17	C18	C19
1	2.61	17.83	7.29	11.88	12.03	25.47	28.15	72.05	25.10
2	3.42	17.15	5.93	18.11	12.62	23.30	23.52	58.68	25.34

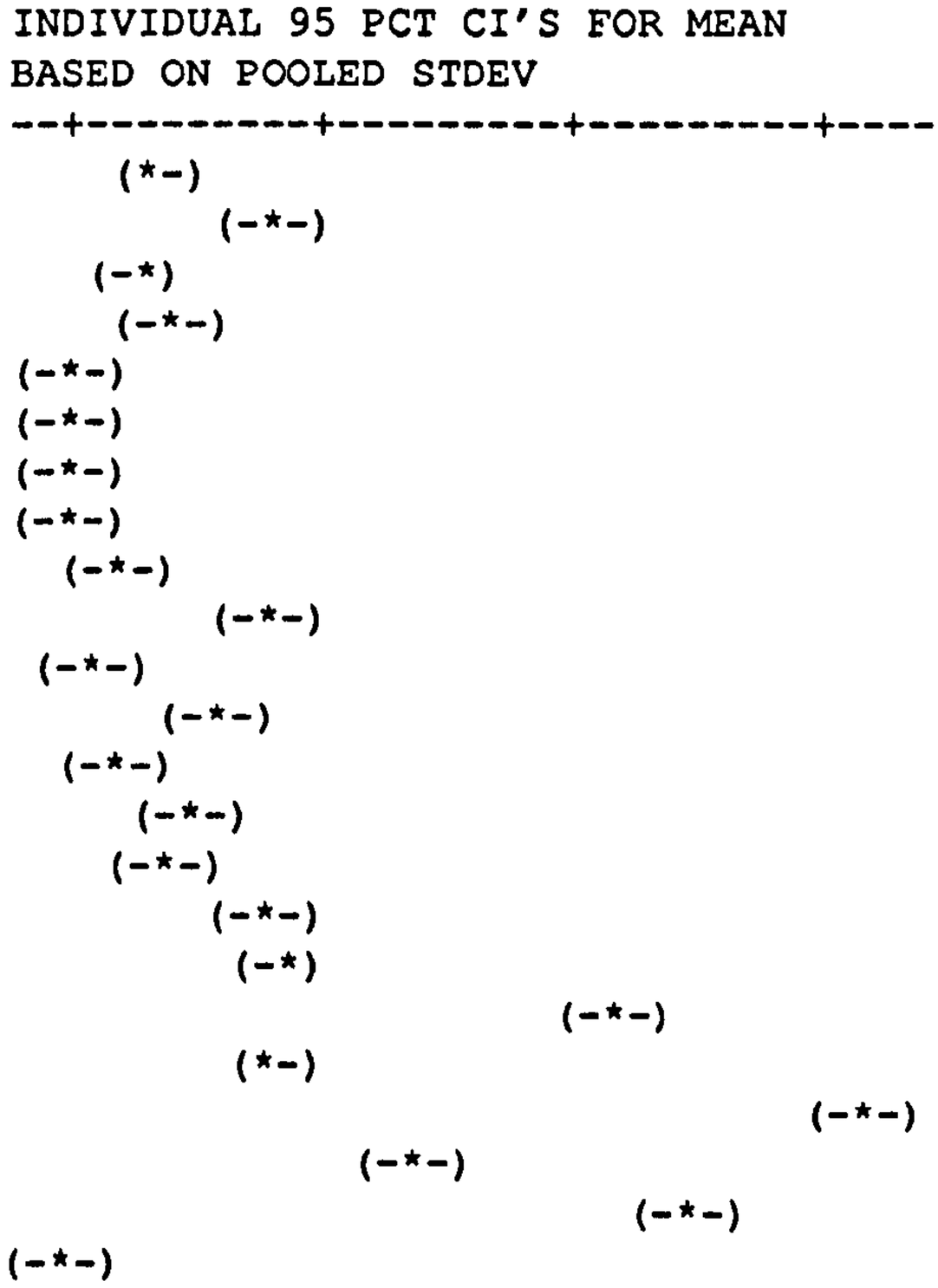
ROW	C20	C21	C22	C23
1	97.35	43.81	83.36	0
2	96.66	40.63	65.14	0

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	22	28937.5	1315.3	92.48**
ERROR	23	327.1	14.2	
TOTAL	45	29264.6		

LEVEL	N	MEAN	STDEV
C1	2	10.40	3.19
C2	2	23.08	3.86
C3	2	7.66	0.23
C4	2	11.47	1.12
C5	2	0.32	0.09
C6	2	0.48	0.04
C7	2	0.23	0.08
C8	2	0.35	0.04
C9	2	6.91	0.08
C10	2	23.10	2.43
C11	2	3.01	0.57
C12	2	17.49	0.48
C13	2	6.61	0.96
C14	2	14.99	4.41
C15	2	12.32	0.42
C16	2	24.38	1.53
C17	2	25.83	3.27
C18	2	65.36	9.45
C19	2	25.22	0.17
C20	2	97.00	0.49
C21	2	42.22	2.25
C22	2	74.25	12.88
C23	2	0.00	0.00

POOLED STDEV = 3.77



* C1-C23 are respectively, PVA1 (0.2%), PVA1 (0.4%), PVA2 (0.2%), PVA2 (0.4%), PEG3 (0.2%), PEG3 (0.4%), PEG4 (0.2%), PEG4 (0.4%), V1 (0.05 l m-2), V1 (0.10 l m-2), V2 (0.05 l m-2), V2 (0.10 l m-2), V3 (0.05 l m-2), V3 (0.10 l m-2), F.E. (0.2 l m-2), F.E. (0.4 l m-2), B.E. (0.5 l m-2), B.E. (1.0 l m-2), Aq1 (0.33%), Aq1 (0.66%), Aq2 (200 gm m-2), Aq2 (250 gm m-2), and Control.
* The pooled, i.e. combined estimate of error is based on the assumption that error for (within) each treatment is the same (in the population).

Table 5.15: Statistical Analysis of the Air-Dry Sand Aggregates Percentages > 0.5 mm in Diameter (Eucalyptus Experiment).

ROW	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
1	5.17	10.49	9.33	9.77	3.78	7.68	1.41	6.07	0.78	0.96
2	7.75	7.20	6.56	9.15	6.08	6.51	1.22	7.39	0.82	1.20

ROW	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20
1	1.67	0.99	4.36	5.79	0.98	5.71	20.02	82.29	5.41	90.31
2	0.68	1.37	7.08	6.71	1.91	3.60	25.95	77.99	3.09	84.43

C21
2.61
1.52

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	20	23161.21	1158.06	338.90**
ERROR	21	71.76	3.42	
TOTAL	41	23232.97		

LEVEL	N	MEAN	STDEV	INDIVIDUAL 95 PCT CI'S FOR MEAN BASED ON POOLED STDEV
C1	2	6.460	1.824	(-*)
C2	2	8.845	2.326	(-*)
C3	2	7.945	1.959	(*)
C4	2	9.460	0.438	(*)
C5	2	4.930	1.626	(*)
C6	2	7.095	0.827	(*)
C7	2	1.315	0.134	(-*)
C8	2	6.730	0.933	(*)
C9	2	0.800	0.028	(*)
C10	2	1.080	0.170	(*-)
C11	2	1.175	0.700	(*-)
C12	2	1.180	0.269	(*-)
C13	2	5.720	1.923	(*)
C14	2	6.250	0.651	(*-)
C15	2	1.445	0.658	(-*)
C16	2	4.655	1.492	(*)
C17	2	22.985	4.193	(*)
C18	2	80.140	3.041	(*)
C19	2	4.250	1.640	(*)
C20	2	87.370	4.158	(*)
C21	2	2.065	0.771	(*)
POOLED STDEV =		1.849		0 25 50 75

* C1-C21 are respectively, PVA1 (0.2%), PVA1 (0.4%), PVA2 (0.2%), PVA2 (0.4%), PEG3 (0.2%), PEG3 (0.4%), PEG4 (0.2%), PEG4 (0.4%), V1 (0.05 l m-2), V1 (0.10 l m-2), V2 (0.05 l m-2), V2 (0.10 l m-2), V3 (0.05 l m-2), V3 (0.10 l m-2), F.E. (0.2 l m-2), F.E. (0.4 l m-2), B.E. (0.5 l m-2), B.E. (1.0 l m-2), Aq1 (0.33%), Aq1 (0.66%), and Control.
* The pooled, i.e. combined estimate of error is based on the assumption that error for (within) each treatment is the same (in the population).

Table 5.16: Statistical Analysis of the Water Stable Sand Aggregates Percentages > 0.5 mm in Diameter (Eucalyptus Experiment).

ROW	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
1	2.78	9.24	8.58	9.68	2.92	6.56	0.94	5.79	0.72	0.43
2	6.16	6.63	6.04	8.30	5.25	6.28	0.37	7.21	0.74	0.88

ROW	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20
1	0.99	0.98	3.62	5.70	0.80	5.69	18.76	80.05	3.96	86.38
2	0.63	1.34	5.03	6.44	1.85	3.31	25.92	73.11	2.45	83.80

C21
1.97
1.00

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	20	21853.93	1092.70	298.95**
ERROR	21	76.76	3.66	
TOTAL	41	21930.68		

LEVEL	N	MEAN	STDEV	INDIVIDUAL 95 PCT CI'S FOR MEAN BASED ON POOLED STDEV
C1	2	4.470	2.390	(*)
C2	2	7.935	1.846	(*)
C3	2	7.310	1.796	(*)
C4	2	8.990	0.976	(-*)
C5	2	4.085	1.648	(*)
C6	2	6.420	0.198	(-*)
C7	2	0.655	0.403	(*)
C8	2	6.500	1.004	(-*)
C9	2	0.730	0.014	(*)
C10	2	0.655	0.318	(*)
C11	2	0.810	0.255	(*)
C12	2	1.160	0.255	(*-)
C13	2	4.325	0.997	(*)
C14	2	6.070	0.523	(*-)
C15	2	1.325	0.742	(-*)
C16	2	4.500	1.683	(*)
C17	2	22.340	5.063	(*)
C18	2	76.580	4.907	(*)
C19	2	3.205	1.068	(*)
C20	2	85.090	1.824	(*)
C21	2	1.485	0.686	(-*)
				-+---------+---------+---------+-----
POOLED STDEV =		1.912		0 25 50 75

* C1-C21 are respectively, PVA1 (0.2%), PVA1 (0.4%), PVA2 (0.2%), PVA2 (0.4%), PEG3 (0.2%), PEG3 (0.4%), PEG4 (0.2%), PEG4 (0.4%), V1 (0.05 l m-2), V1 (0.10 l m-2), V2 (0.05 l m-2), V2 (0.10 l m-2), V3 (0.05 l m-2), V3 (0.10 l m-2), F.E. (0.2 l m-2), F.E. (0.4 l m-2), B.E. (0.5 l m-2), B.E. (1.0 l m-2), Aq1 (0.33%), Aq1 (0.66%), and Control.
* The pooled, i.e. combined estimate of error is based on the assumption that error for (within) each treatment is the same (in the population).

Table 5.17: Statistical Analysis of the Merlinda spp. Germinations Number After 6 Days from Cultivation in Druridge Bay Dunes Sand.

ROW	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
1	12	5	4	13	10	12	6	17	13	15	3	9
2	5	2	17	17	13	14	17	20	22	20	12	6
3	1	1	1	13	15	12	13	12	21	3	14	3

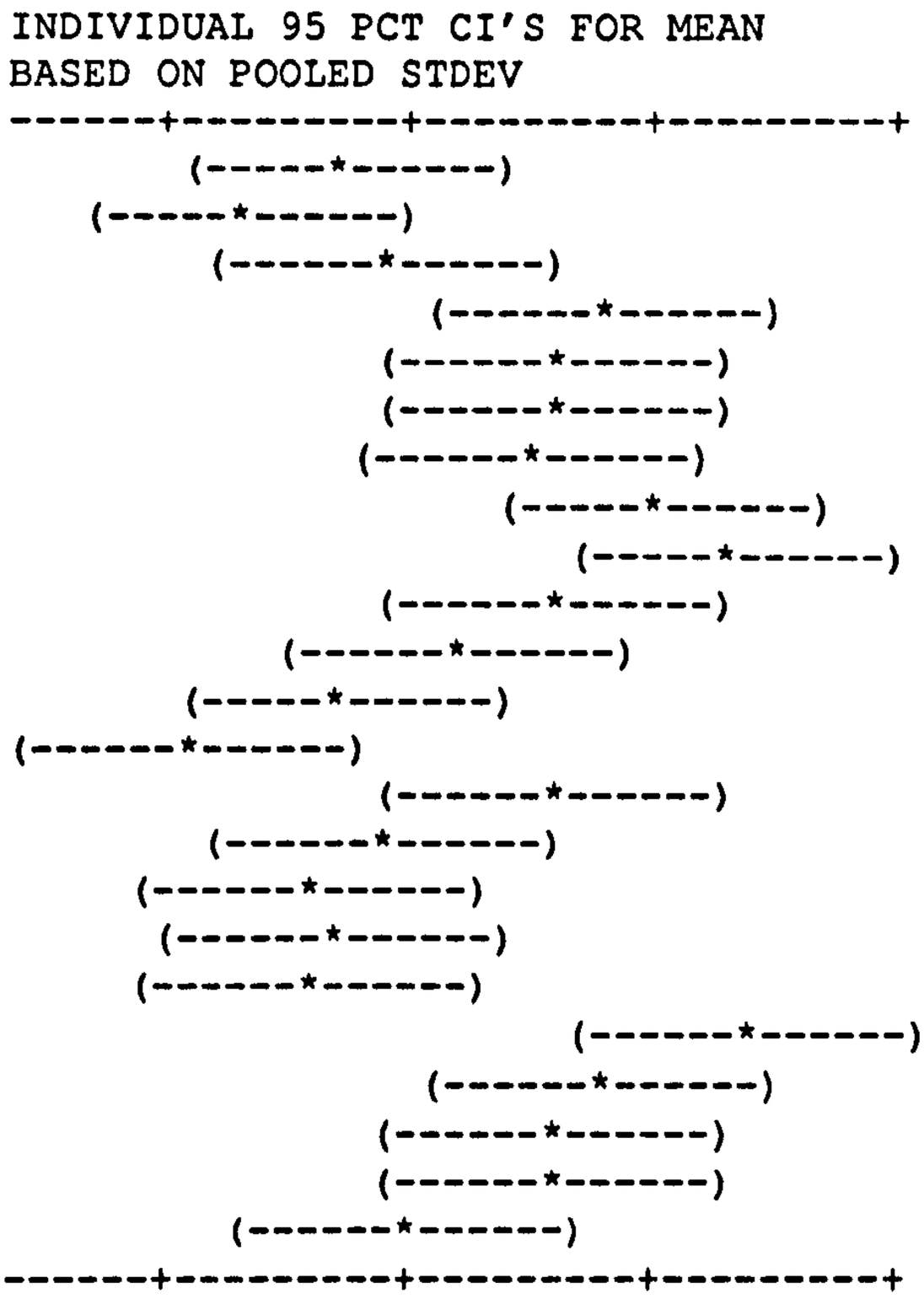
ROW	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
1	0	8	11	5	1	3	19	6	10	8	6
2	1	13	2	9	11	3	20	20	17	14	8
3	1	18	9	1	5	9	18	17	11	16	10

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	22	1624.5	73.8	3.37
ERROR	46	1008.0	21.9	
TOTAL	68	2632.5		

LEVEL	N	MEAN	STDEV
C1	3	6.000	5.568
C2	3	2.667	2.082
C3	3	7.333	8.505
C4	3	14.333	2.309
C5	3	12.667	2.517
C6	3	12.667	1.155
C7	3	12.000	5.568
C8	3	16.333	4.041
C9	3	18.667	4.933
C10	3	12.667	8.737
C11	3	9.667	5.859
C12	3	6.000	3.000
C13	3	0.667	0.577
C14	3	13.000	5.000
C15	3	7.333	4.726
C16	3	5.000	4.000
C17	3	5.667	5.033
C18	3	5.000	3.464
C19	3	19.000	1.000
C20	3	14.333	7.371
C21	3	12.667	3.786
C22	3	12.667	4.163
C23	3	8.000	2.000

POOLED STDEV = 4.681



* C1-C23 are respectively, PVA1 (0.2%), PVA1 (0.4%), PVA2 (0.2%), PVA2 (0.4%), PEG3 (0.2%), PEG3 (0.4%), PEG4 (0.2%), PEG4 (0.4%), V1 (0.05 l m-2), V1 (0.10 l m-2), V2 (0.05 l m-2), V2 (0.10 l m-2), V3 (0.05 l m-2), V3 (0.10 l m-2), F.E. (0.2 l m-2), F.E. (0.4 l m-2), B.E. (0.5 l m-2), B.E. (1.0 l m-2), Aq1 (0.33%), Aq1 (0.66%), Aq2 (200 gm m-2), Aq2 (250 gm m-2), and Control.
* The pooled, i.e. combined estimate of error is based on the assumption that error for (within) each treatment is the same (in the population).

Table 5.18: Statistical Analysis of the Melion spp. Germinations Number After 6 Days from Cultivation in Druridge Bay Dunes Sand.

ROW	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
1	21	10	2	21	3	16	1	9	12	0	10	15
2	15	16	1	19	5	3	0	9	7	7	21	6
3	22	11	15	9	12	11	7	12	3	6	21	16

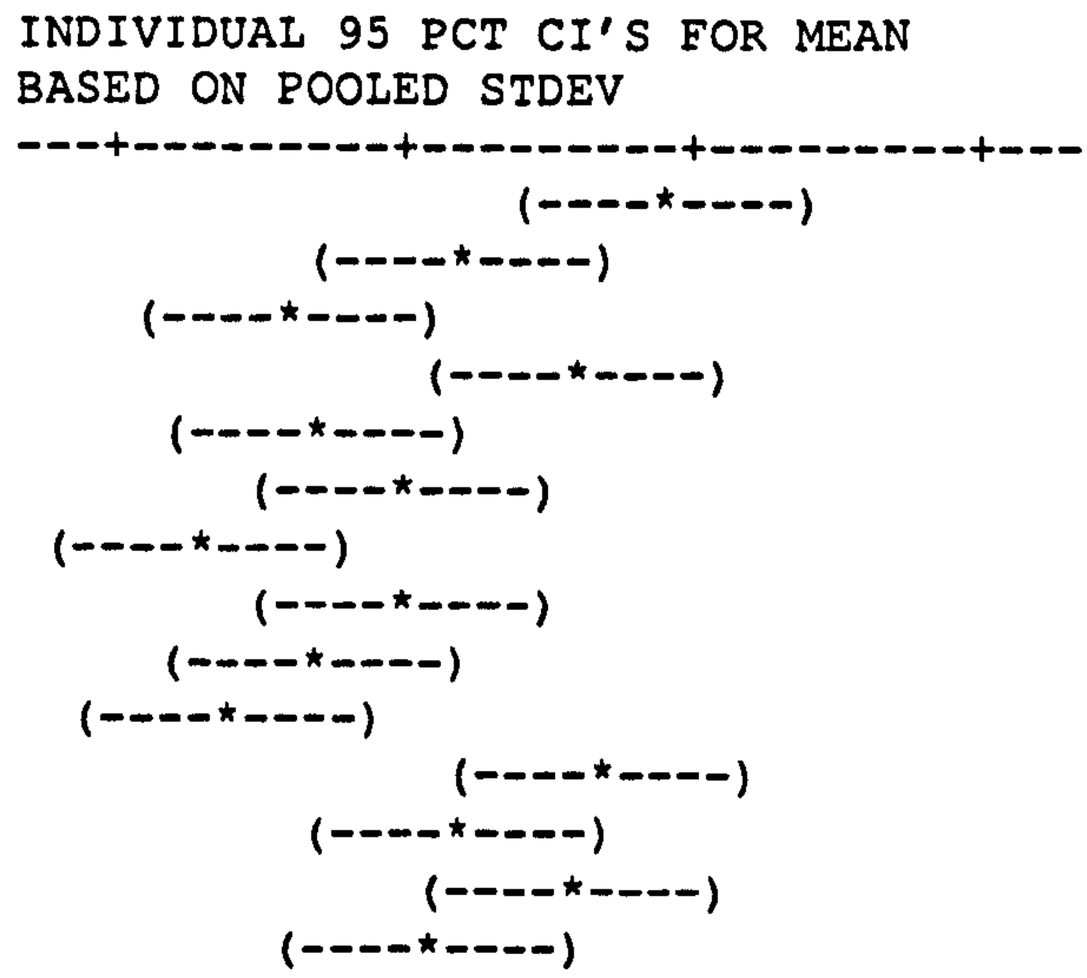
ROW	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
1	14	9	5	2	7	18	21	21	17	10	14
2	15	12	11	4	7	18	22	24	19	14	15
3	20	13	12	10	9	14	21	24	12	22	14

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	22	2076.3	94.4	5.14
ERROR	46	844.0	18.3	
TOTAL	68	2920.3		

LEVEL	N	MEAN	STDEV
C1	3	19.333	3.786
C2	3	12.333	3.215
C3	3	6.000	7.810
C4	3	16.333	6.429
C5	3	6.667	4.726
C6	3	10.000	6.557
C7	3	2.667	3.786
C8	3	10.000	1.732
C9	3	7.333	4.509
C10	3	4.333	3.786
C11	3	17.333	6.351
C12	3	12.333	5.508
C13	3	16.333	3.215
C14	3	11.333	2.082
C15	3	9.333	3.786
C16	3	5.333	4.163
C17	3	7.667	1.155
C18	3	16.667	2.309
C19	3	21.333	0.577
C20	3	23.000	1.732
C21	3	16.000	3.606
C22	3	15.333	6.110
C23	3	14.333	0.577

POOLED STDEV = 4.283



* C1-C23 are respectively, PVA1 (0.2%), PVA1 (0.4%), PVA2 (0.2%), PVA2 (0.4%), PEG3 (0.2%), PEG3 (0.4%), PEG4 (0.2%), PEG4 (0.4%), V1 (0.05 l m-2), V1 (0.10 l m-2), V2 (0.05 l m-2), V2 (0.10 l m-2), V3 (0.05 l m-2), V3 (0.10 l m-2), F.E. (0.2 l m-2), F.E. (0.4 l m-2), B.E. (0.5 l m-2), B.E. (1.0 l m-2), Aq1 (0.33%), Aq1 (0.66%), Aq2 (200 gm m-2), Aq2 (250 gm m-2), and Control.
* The pooled, i.e. combined estimate of error is based on the assumption that error for (within) each treatment is the same (in the population).

Table 5.19: Statistical Analysis of the Merlinda spp. Germinations Number After 21 Days from Cultivation in Druridge Bay Dunes Sand.

ROW	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
1	25	23	24	24	23	24	25	22	24	22	23	20
2	23	24	21	24	23	23	25	23	23	25	22	22
3	21	24	23	23	22	24	25	25	25	23	25	22

ROW	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
1	23	23	23	23	23	22	24	23	24	20	23
2	23	23	25	23	23	23	23	23	24	17	24
3	21	24	25	25	22	18	22	23	18	20	23

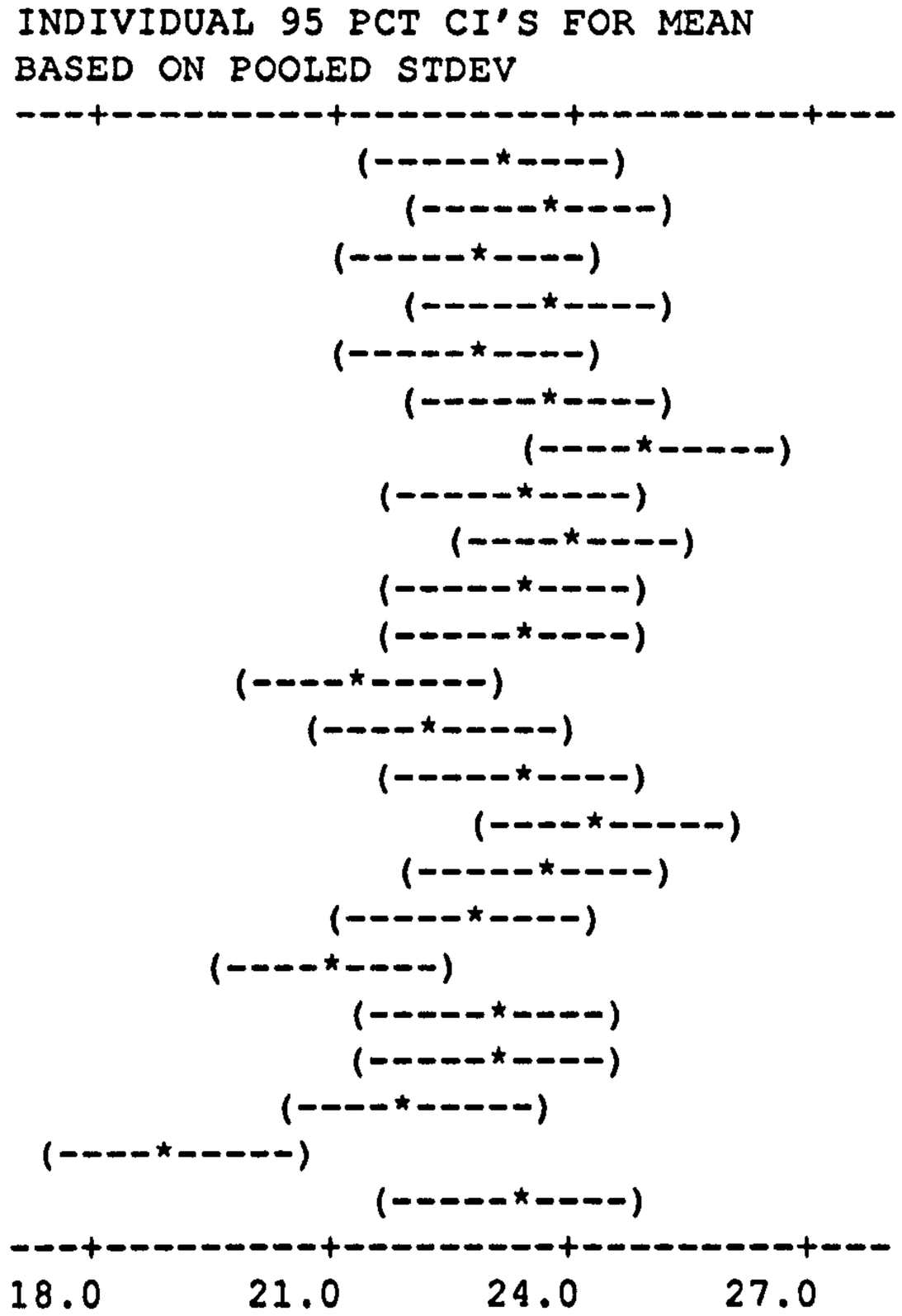
ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	22	100.64	4.57	2.34
ERROR	46	90.00	1.96	
TOTAL	68	190.64		

LEVEL	N	MEAN	STDEV
C1	3	23.000	2.000
C2	3	23.667	0.577
C3	3	22.667	1.528
C4	3	23.667	0.577
C5	3	22.667	0.577
C6	3	23.667	0.577
C7	3	25.000	0.000
C8	3	23.333	1.528
C9	3	24.000	1.000
C10	3	23.333	1.528
C11	3	23.333	1.528
C12	3	21.333	1.155
C13	3	22.333	1.155
C14	3	23.333	0.577
C15	3	24.333	1.155
C16	3	23.667	1.155
C17	3	22.667	0.577
C18	3	21.000	2.646
C19	3	23.000	1.000
C20	3	23.000	0.000
C21	3	22.000	3.464
C22	3	19.000	1.732
C23	3	23.333	0.577

POOLED STDEV = 1.399

INDIVIDUAL 95 PCT CI'S FOR MEAN BASED ON POOLED STDEV



* C1-C23 are respectively, PVA1 (0.2%), PVA1 (0.4%), PVA2 (0.2%), PVA2 (0.4%), PEG3 (0.2%), PEG3 (0.4%), PEG4 (0.2%), PEG4 (0.4%), V1 (0.05 l m-2), V1 (0.10 l m-2), V2 (0.05 l m-2), V2 (0.10 l m-2), V3 (0.05 l m-2), V3 (0.10 l m-2), F.E. (0.2 l m-2), F.E. (0.4 l m-2), B.E. (0.5 l m-2), B.E. (1.0 l m-2), Aq1 (0.33%), Aq1 (0.66%), Aq2 (200 gm m-2), Aq2 (250 gm m-2), and Control.
* The pooled, i.e. combined estimate of error is based on the assumption that error for (within) each treatment is the same (in the population).

Table 5.20: Statistical Analysis of the Melion spp. Germinations Number After 21 Days from Cultivation in Druridge Bay Dunes Sand.

ROW	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
1	22	22	23	24	25	22	24	24	23	24	21	25
2	22	21	22	23	24	24	24	24	23	21	24	24
3	25	22	24	23	24	22	22	25	22	23	23	23

ROW	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
1	25	22	24	25	21	25	23	23	19	19	23
2	21	25	25	23	23	23	24	24	21	23	24
3	23	24	25	25	25	24	21	25	22	23	25

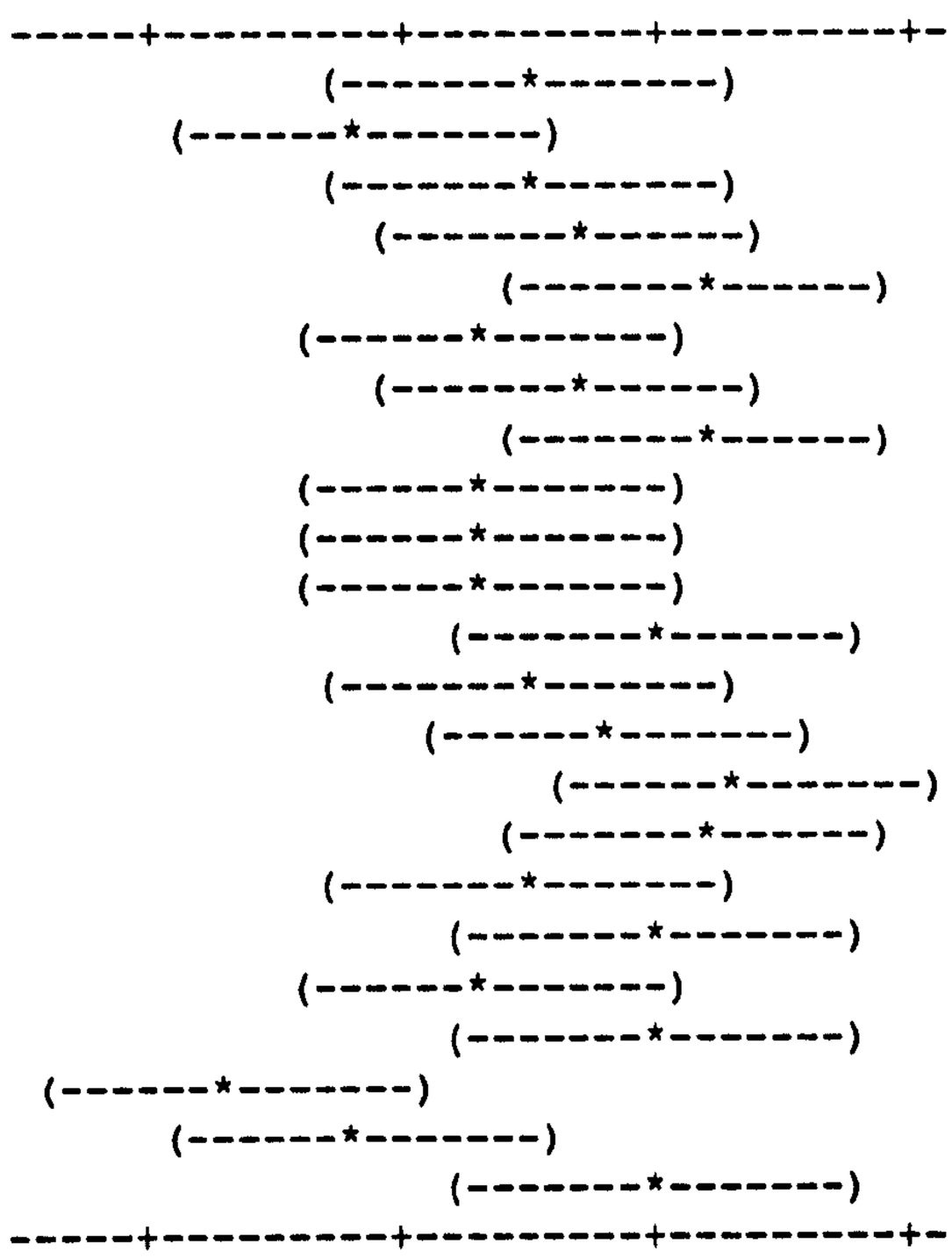
ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	22	64.55	2.93	1.73
ERROR	46	78.00	1.70	
TOTAL	68	142.55		

LEVEL	N	MEAN	STDEV
C1	3	23.000	1.732
C2	3	21.667	0.577
C3	3	23.000	1.000
C4	3	23.333	0.577
C5	3	24.333	0.577
C6	3	22.667	1.155
C7	3	23.333	1.155
C8	3	24.333	0.577
C9	3	22.667	0.577
C10	3	22.667	1.528
C11	3	22.667	1.528
C12	3	24.000	1.000
C13	3	23.000	2.000
C14	3	23.667	1.528
C15	3	24.667	0.577
C16	3	24.333	1.155
C17	3	23.000	2.000
C18	3	24.000	1.000
C19	3	22.667	1.528
C20	3	24.000	1.000
C21	3	20.667	1.528
C22	3	21.667	2.309
C23	3	24.000	1.000

POOLED STDEV = 1.302

INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV



* C1-C23 are respectively, PVA1 (0.2%), PVA1 (0.4%), PVA2 (0.2%), PVA2 (0.4%), PEG3 (0.2%), PEG3 (0.4%), PEG4 (0.2%), PEG4 (0.4%), V1 (0.05 l m-2), V1 (0.10 l m-2), V2 (0.05 l m-2), V2 (0.10 l m-2), V3 (0.05 l m-2), V3 (0.10 l m-2), F.E. (0.2 l m-2), F.E. (0.4 l m-2), B.E. (0.5 l m-2), B.E. (1.0 l m-2), Aq1 (0.33%), Aq1 (0.66%), Aq2 (200 gm m-2), Aq2 (250 gm m-2), and Control.
* The pooled, i.e. combined estimate of error is based on the assumption that error for (within) each treatment is the same (in the population).

Table 5.21: Statistical Analysis of the Marram Grass Germinations Number After 9 Days from Cultivation in Druridge Bay Dunes Sand.

ROW	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
1	0	0	0	9	8	2	13	1	8	1	8	0
2	0	0	12	6	12	14	14	11	6	9	6	3
3	0	0	6	3	16	6	7	10	5	4	6	1

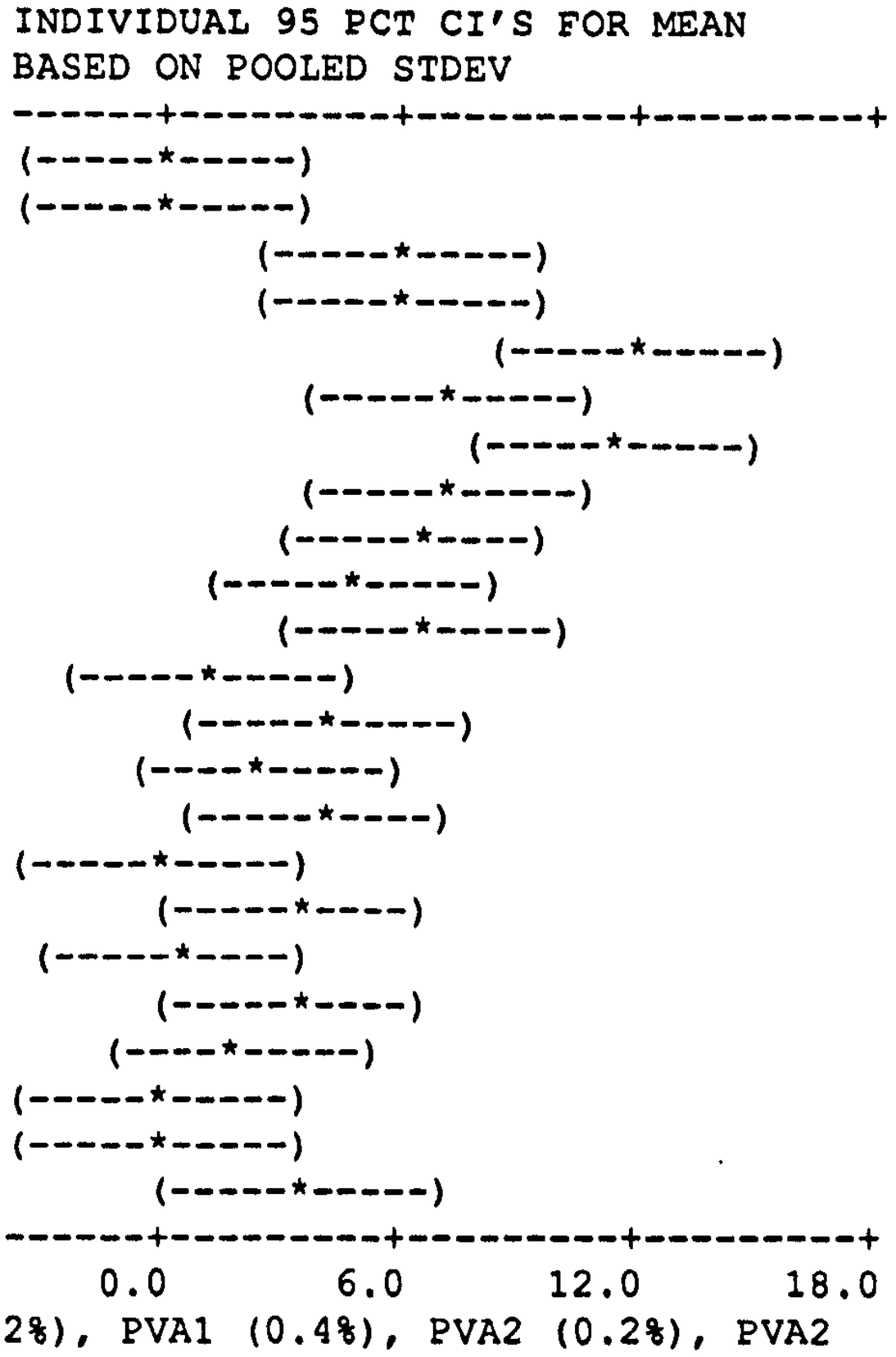
ROW	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
1	8	2	8	0	5	0	4	1	0	0	3
2	2	4	3	0	4	0	5	1	0	0	4
3	3	2	1	0	1	1	1	4	0	0	4

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	22	805.28	36.60	4.16
ERROR	46	404.67	8.80	
TOTAL	68	1209.94		

LEVEL	N	MEAN	STDEV
C1	3	0.000	0.000
C2	3	0.000	0.000
C3	3	6.000	6.000
C4	3	6.000	3.000
C5	3	12.000	4.000
C6	3	7.333	6.110
C7	3	11.333	3.786
C8	3	7.333	5.508
C9	3	6.333	1.528
C10	3	4.667	4.041
C11	3	6.667	1.155
C12	3	1.333	1.528
C13	3	4.333	3.215
C14	3	2.667	1.155
C15	3	4.000	3.606
C16	3	0.000	0.000
C17	3	3.333	2.082
C18	3	0.333	0.577
C19	3	3.333	2.082
C20	3	2.000	1.732
C21	3	0.000	0.000
C22	3	0.000	0.000
C23	3	3.667	0.577

POOLED STDEV = 2.966



* C1-C23 are respectively, PVA1 (0.2%), PVA1 (0.4%), PVA2 (0.2%), PVA2 (0.4%), PEG3 (0.2%), PEG3 (0.4%), PEG4 (0.2%), PEG4 (0.4%), V1 (0.05 l m-2), V1 (0.10 l m-2), V2 (0.05 l m-2), V2 (0.10 l m-2), V3 (0.05 l m-2), V3 (0.10 l m-2), F.E. (0.2 l m-2), F.E. (0.4 l m-2), B.E. (0.5 l m-2), B.E. (1.0 l m-2), Aq1 (0.33%), Aq1 (0.66%), Aq2 (200 gm m-2), Aq2 (250 gm m-2), and Control.
* The pooled, i.e. combined estimate of error is based on the assumption that error for (within) each treatment is the same (in the population).

Table 5.22: Statistical Analysis of the Marram Grass Germinations Number After 12 Days from Cultivation in Druridge Bay Dunes Sand.

ROW	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
1	12	12	20	9	18	12	21	17	19	20	21	13
2	13	12	23	19	21	22	18	21	20	20	21	18
3	3	7	16	14	21	19	21	19	18	20	22	10

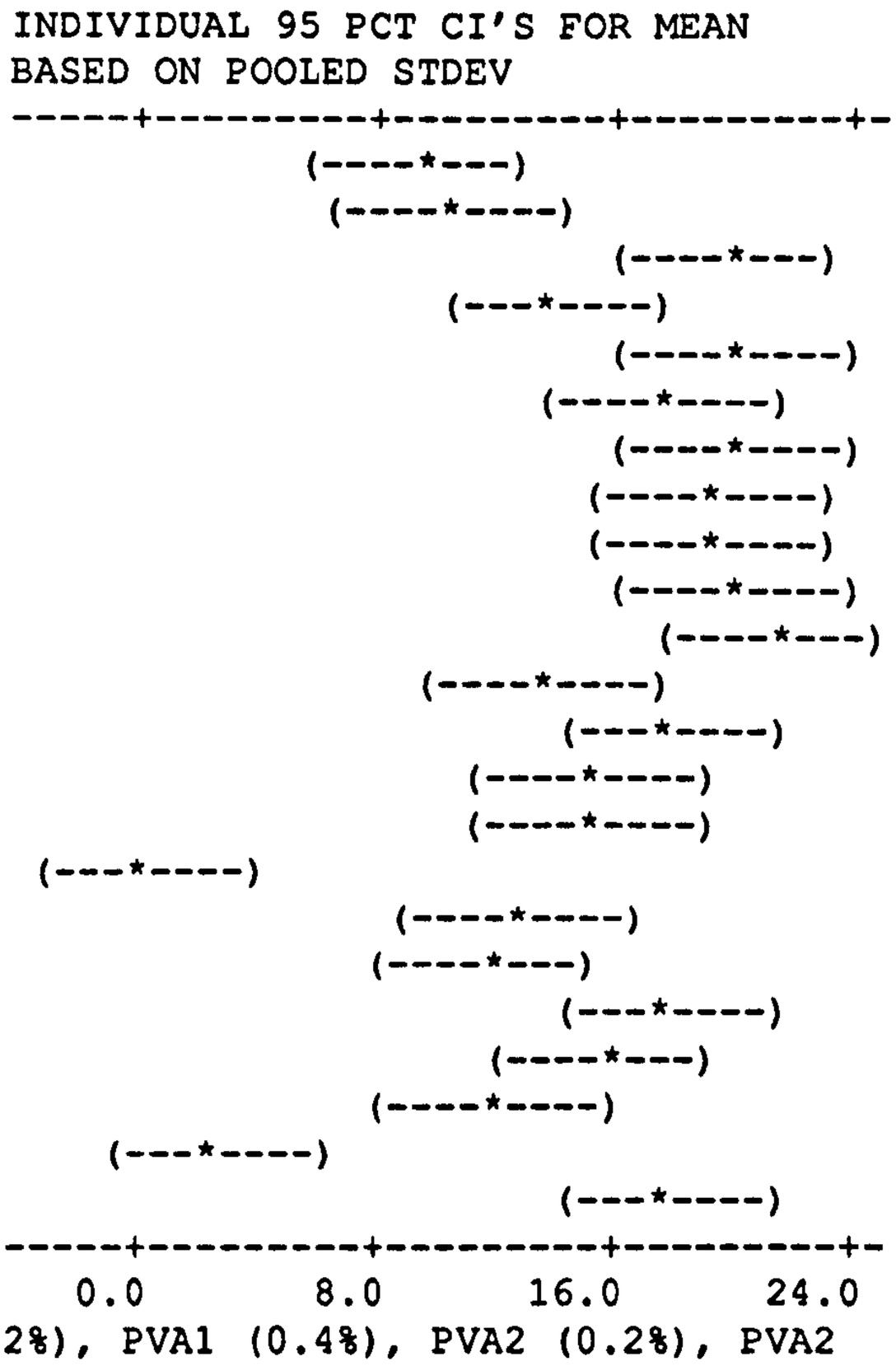
ROW	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
1	20	15	20	0	16	12	17	18	16	1	20
2	17	18	14	0	11	10	22	12	15	2	21
3	17	13	11	1	12	13	15	17	5	5	13

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	22	1954.4	88.8	8.05
ERROR	46	507.3	11.0	
TOTAL	68	2461.8		

LEVEL	N	MEAN	STDEV
C1	3	9.333	5.508
C2	3	10.333	2.887
C3	3	19.667	3.512
C4	3	14.000	5.000
C5	3	20.000	1.732
C6	3	17.667	5.132
C7	3	20.000	1.732
C8	3	19.000	2.000
C9	3	19.000	1.000
C10	3	20.000	0.000
C11	3	21.333	0.577
C12	3	13.667	4.041
C13	3	18.000	1.732
C14	3	15.333	2.517
C15	3	15.000	4.583
C16	3	0.333	0.577
C17	3	13.000	2.646
C18	3	11.667	1.528
C19	3	18.000	3.606
C20	3	15.667	3.215
C21	3	12.000	6.083
C22	3	2.667	2.082
C23	3	18.000	4.359

POOLED STDEV = 3.321



* C1-C23 are respectively, PVA1 (0.2%), PVA1 (0.4%), PVA2 (0.2%), PVA2 (0.4%), PEG3 (0.2%), PEG3 (0.4%), PEG4 (0.2%), PEG4 (0.4%), V1 (0.05 l m-2), V1 (0.10 l m-2), V2 (0.05 l m-2), V2 (0.10 l m-2), V3 (0.05 l m-2), V3 (0.10 l m-2), F.E. (0.2 l m-2), F.E. (0.4 l m-2), B.E. (0.5 l m-2), B.E. (1.0 l m-2), Aq1 (0.33%), Aq1 (0.66%), Aq2 (200 gm m-2), Aq2 (250 gm m-2), and Control.

* The pooled, i.e. combined estimate of error is based on the assumption that error for (within) each treatment is the same (in the population).

Table 5.23: Statistical Analysis of the Marram Grass Germinations Number After 21 Days from Cultivation in Druridge Bay Dunes Sand.

ROW	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
1	24	23	22	23	18	17	21	20	21	21	24	21
2	22	21	24	23	22	22	19	23	25	20	22	22
3	23	19	20	22	21	19	23	21	20	23	24	20

ROW	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
1	23	21	21	20	20	25	20	23	21	15	20
2	21	22	22	20	20	22	23	19	24	20	21
3	18	22	18	15	22	18	20	24	21	20	19

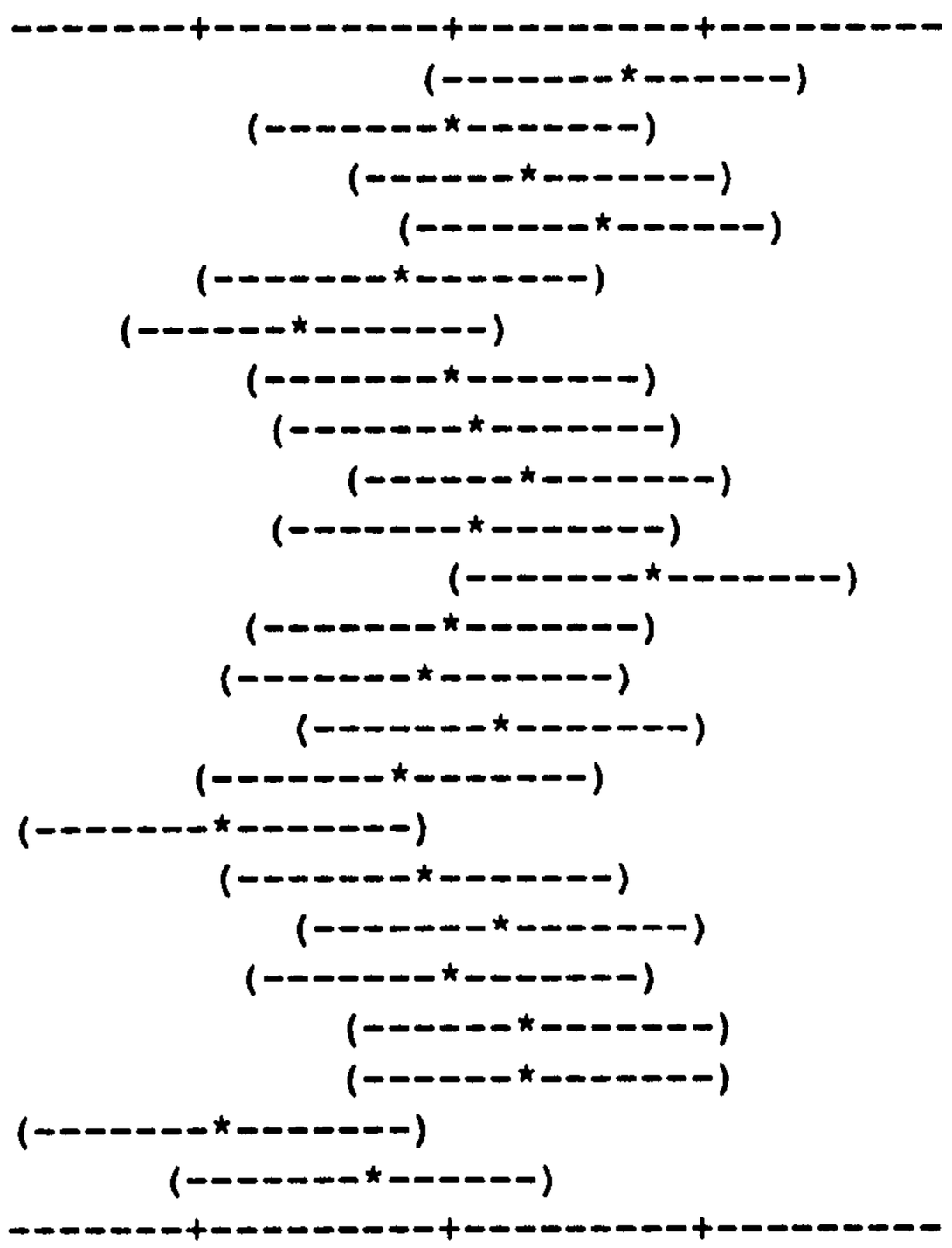
ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	22	108.81	4.95	1.22
ERROR	46	186.67	4.06	
TOTAL	68	295.48		

LEVEL	N	MEAN	STDEV
C1	3	23.000	1.000
C2	3	21.000	2.000
C3	3	22.000	2.000
C4	3	22.667	0.577
C5	3	20.333	2.082
C6	3	19.333	2.517
C7	3	21.000	2.000
C8	3	21.333	1.528
C9	3	22.000	2.646
C10	3	21.333	1.528
C11	3	23.333	1.155
C12	3	21.000	1.000
C13	3	20.667	2.517
C14	3	21.667	0.577
C15	3	20.333	2.082
C16	3	18.333	2.887
C17	3	20.667	1.155
C18	3	21.667	3.512
C19	3	21.000	1.732
C20	3	22.000	2.646
C21	3	22.000	1.732
C22	3	18.333	2.887
C23	3	20.000	1.000

POOLED STDEV = 2.014

INDIVIDUAL 95 PCT CI'S FOR MEAN BASED ON POOLED STDEV



* C1-C23 are respectively, PVA1 (0.2%), PVA1 (0.4%), PVA2 (0.2%), PVA2 (0.4%), PEG3 (0.2%), PEG3 (0.4%), PEG4 (0.2%), PEG4 (0.4%), V1 (0.05 l m-2), V1 (0.10 l m-2), V2 (0.05 l m-2), V2 (0.10 l m-2), V3 (0.05 l m-2), V3 (0.10 l m-2), F.E. (0.2 l m-2), F.E. (0.4 l m-2), B.E. (0.5 l m-2), B.E. (1.0 l m-2), Aq1 (0.33%), Aq1 (0.66%), Aq2 (200 gm m-2), Aq2 (250 gm m-2), and Control.
* The pooled, i.e. combined estimate of error is based on the assumption that error for (within) each treatment is the same (in the population).

Table 5.24: Statistical Analysis of the Panicum spp. Germinations Number After 9 Days from Cultivation in Druridge Bay Dunes Sand.

ROW	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
1	0	1	0	1	0	0	0	1	0	3	0	0
2	2	0	0	0	1	0	2	2	0	2	0	3
3	0	0	0	1	0	0	0	1	0	2	0	3

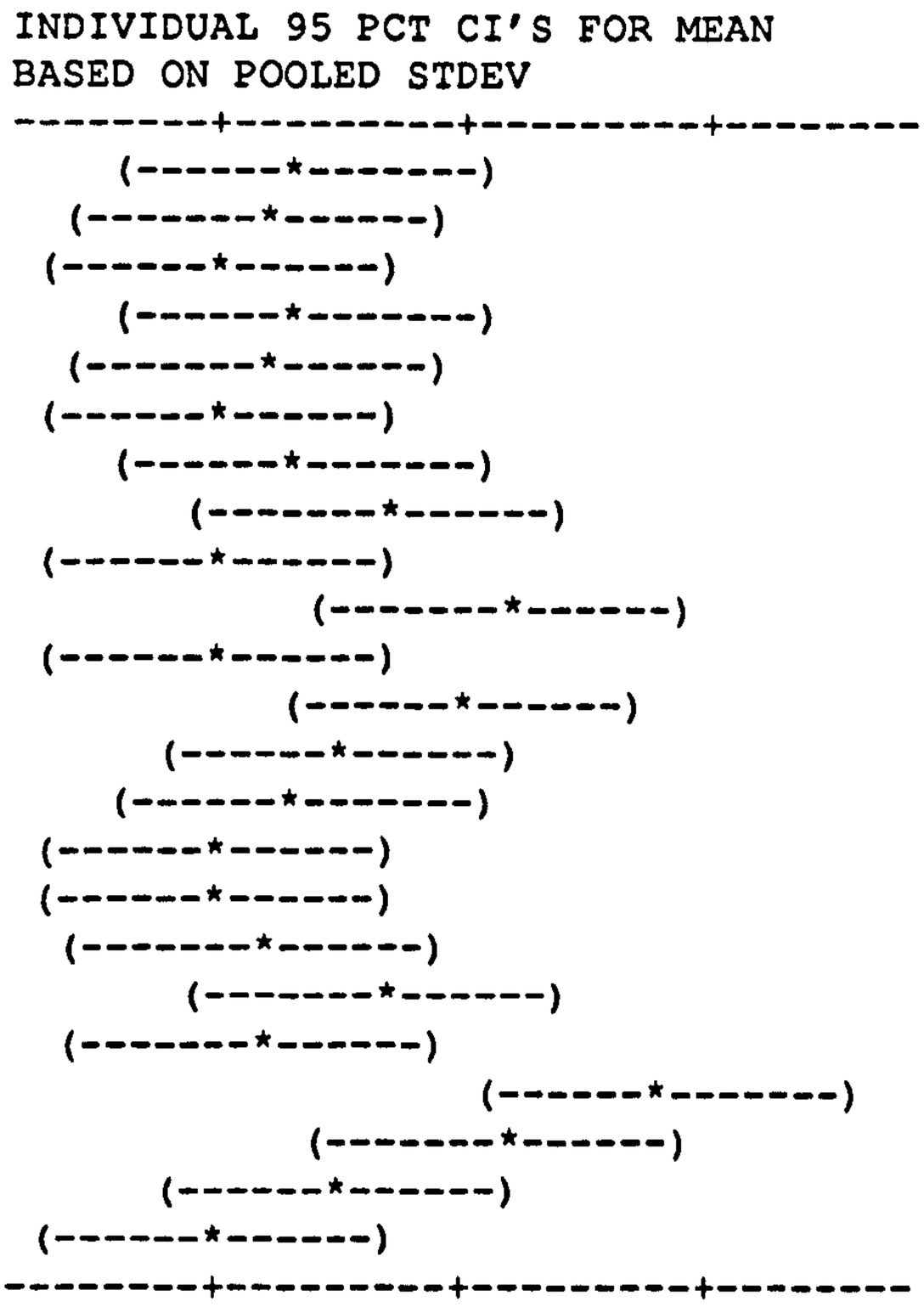
ROW	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
1	2	0	0	0	0	1	1	0	1	0	0
2	1	0	0	0	1	1	0	9	4	1	0
3	0	2	0	0	0	2	0	2	2	2	0

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	22	61.25	2.78	1.76
ERROR	46	72.67	1.58	
TOTAL	68	133.91		

LEVEL	N	MEAN	STDEV
C1	3	0.667	1.155
C2	3	0.333	0.577
C3	3	0.000	0.000
C4	3	0.667	0.577
C5	3	0.333	0.577
C6	3	0.000	0.000
C7	3	0.667	1.155
C8	3	1.333	0.577
C9	3	0.000	0.000
C10	3	2.333	0.577
C11	3	0.000	0.000
C12	3	2.000	1.732
C13	3	1.000	1.000
C14	3	0.667	1.155
C15	3	0.000	0.000
C16	3	0.000	0.000
C17	3	0.333	0.577
C18	3	1.333	0.577
C19	3	0.333	0.577
C20	3	3.667	4.726
C21	3	2.333	1.528
C22	3	1.000	1.000
C23	3	0.000	0.000

POOLED STDEV = 1.257



* C1-C23 are respectively, PVA1 (0.2%), PVA1 (0.4%), PVA2 (0.2%), PVA2 (0.4%), PEG3 (0.2%), PEG3 (0.4%), PEG4 (0.2%), PEG4 (0.4%), V1 (0.05 l m-2), V1 (0.10 l m-2), V2 (0.05 l m-2), V2 (0.10 l m-2), V3 (0.05 l m-2), V3 (0.10 l m-2), F.E. (0.2 l m-2), F.E. (0.4 l m-2), B.E. (0.5 l m-2), B.E. (1.0 l m-2), Aq1 (0.33%), Aq1 (0.66%), Aq2 (200 gm m-2), Aq2 (250 gm m-2), and Control.

* The pooled, i.e. combined estimate of error is based on the assumption that error for (within) each treatment is the same (in the population).

Table 5.25: Statistical Analysis of the Panicum spp. Germinations Number After 21 Days from Cultivation in Druridge Bay Dunes Sand.

ROW	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
1	4	2	4	6	4	0	2	2	4	6	3	6	4
2	4	5	2	2	4	4	6	6	10	5	0	3	2
3	2	4	4	1	3	1	1	4	3	3	7	3	2

ROW	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
1	2	0	2	3	5	3	3	2	0	7
2	8	5	7	1	8	2	14	4	1	9
3	3	4	3	1	6	2	3	2	2	6

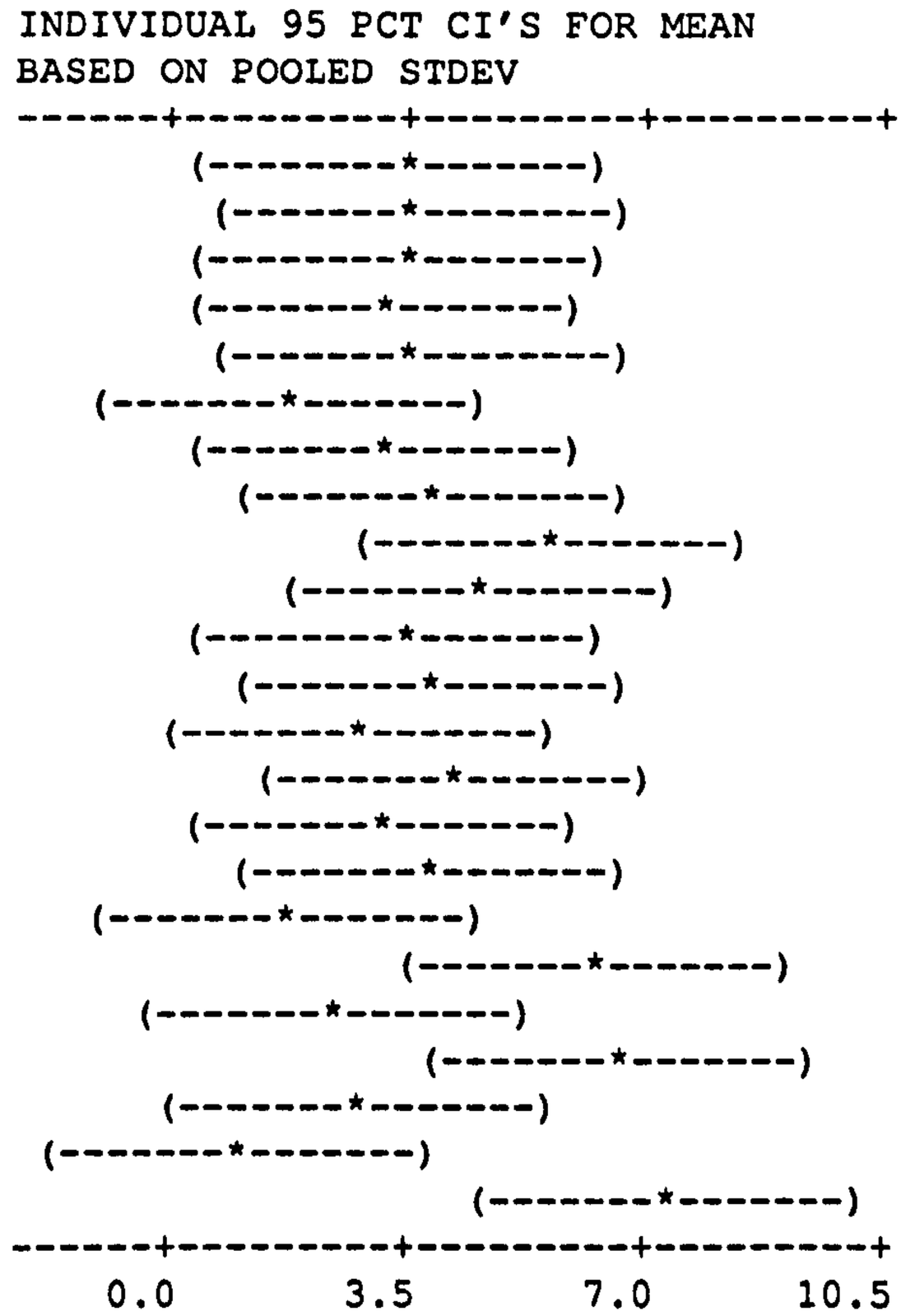
ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	22	167.54	7.62	1.30
ERROR	46	268.67	5.84	
TOTAL	68	436.20		

LEVEL	N	MEAN	STDEV
C1	3	3.333	1.155
C2	3	3.667	1.528
C3	3	3.333	1.155
C4	3	3.000	2.646
C5	3	3.667	0.577
C6	3	1.667	2.082
C7	3	3.000	2.646
C8	3	4.000	2.000
C9	3	5.667	3.786
C10	3	4.667	1.528
C11	3	3.333	3.512
C12	3	4.000	1.732
C13	3	2.667	1.155
C14	3	4.333	3.215
C15	3	3.000	2.646
C16	3	4.000	2.646
C17	3	1.667	1.155
C18	3	6.333	1.528
C19	3	2.333	0.577
C20	3	6.667	6.351
C21	3	2.667	1.155
C22	3	1.000	1.000
C23	3	7.333	1.528

POOLED STDEV = 2.417

INDIVIDUAL 95 PCT CI'S FOR MEAN BASED ON POOLED STDEV



* C1-C23 are respectively, PVA1 (0.2%), PVA1 (0.4%), PVA2 (0.2%), PVA2 (0.4%), PEG3 (0.2%), PEG3 (0.4%), PEG4 (0.2%), PEG4 (0.4%), V1 (0.05 l m-2), V1 (0.10 l m-2), V2 (0.05 l m-2), V2 (0.10 l m-2), V3 (0.05 l m-2), V3 (0.10 l m-2), F.E. (0.2 l m-2), F.E. (0.4 l m-2), B.E. (0.5 l m-2), B.E. (1.0 l m-2), Aq1 (0.33%), Aq1 (0.66%), Aq2 (200 gm m-2), Aq2 (250 gm m-2), and Control.
* The pooled, i.e. combined estimate of error is based on the assumption that error for (within) each treatment is the same (in the population).

Table 5.26: Statistical Analysis of the Merlinda spp. Oven-Dry Shoots and Roots.

ROW	C1	C2	C3	C4	C5	C6	C7	C8
1	0.2117	0.2254	0.2109	0.2056	0.1929	0.2521	0.2387	0.1681
2	0.2565	0.1820	0.2527	0.2480	0.2376	0.1945	0.2191	0.2018
3	0.2205	0.1907	0.2171	0.2015	0.1930	0.1708	0.2351	0.1731

ROW	C9	C10	C11	C12	C13	C14	C15	C16
1	0.2012	0.2178	0.1935	0.1581	0.1609	0.1809	0.1370	0.1646
2	0.2478	0.2352	0.2120	0.2161	0.1648	0.1937	0.1924	0.1454
3	0.2156	0.1539	0.2187	0.1993	0.1712	0.2172	0.1729	0.1830

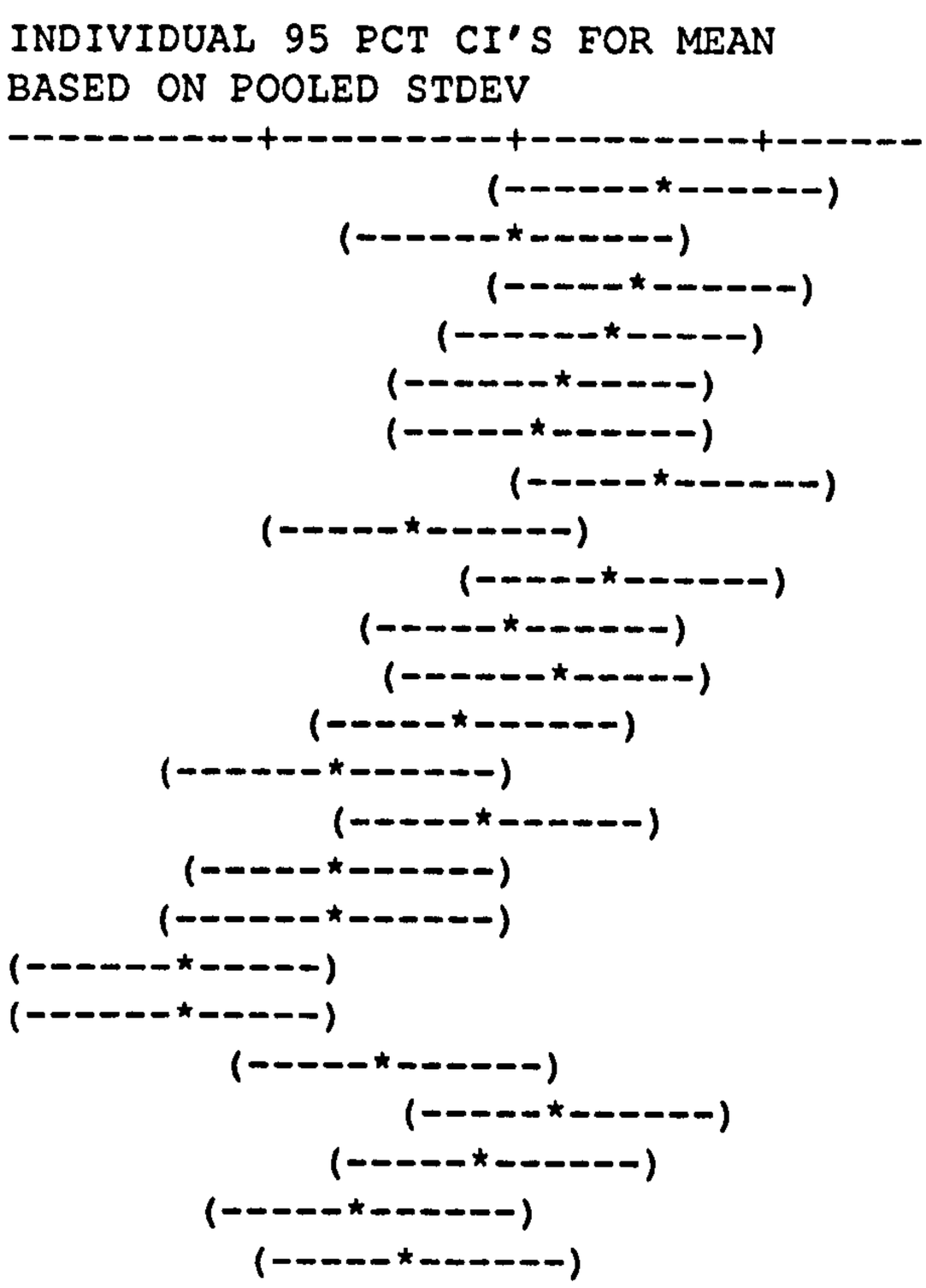
ROW	C17	C18	C19	C20	C21	C22	C23
1	0.1381	0.1387	0.1728	0.2439	0.1485	0.2482	0.1719
2	0.1417	0.1459	0.1616	0.2023	0.2068	0.1285	0.2123
3	0.1224	0.1169	0.1954	0.1865	0.2354	0.1377	0.1602

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	22	0.050031	0.002274	2.79
ERROR	46	0.037483	0.000815	
TOTAL	68	0.087514		

LEVEL	N	MEAN	STDEV
C1	3	0.22957	0.02374
C2	3	0.19937	0.02296
C3	3	0.22690	0.02256
C4	3	0.21837	0.02574
C5	3	0.20783	0.02578
C6	3	0.20580	0.04181
C7	3	0.23097	0.01043
C8	3	0.18100	0.01819
C9	3	0.22153	0.02386
C10	3	0.20230	0.04281
C11	3	0.20807	0.01305
C12	3	0.19117	0.02984
C13	3	0.16563	0.00520
C14	3	0.19727	0.01841
C15	3	0.16743	0.02810
C16	3	0.16433	0.01880
C17	3	0.13407	0.01026
C18	3	0.13383	0.01510
C19	3	0.17660	0.01722
C20	3	0.21090	0.02965
C21	3	0.19690	0.04429
C22	3	0.17147	0.06661
C23	3	0.18147	0.02734

POOLED STDEV = 0.02855



* C1-C23 are respectively, PVA1 (0.2%), PVA1 (0.4%), PVA2 (0.2%), PVA2 (0.4%), PEG3 (0.2%), PEG3 (0.4%), PEG4 (0.2%), PEG4 (0.4%), V1 (0.05 l m-2), V1 (0.10 l m-2), V2 (0.05 l m-2), V2 (0.10 l m-2), V3 (0.05 l m-2), V3 (0.10 l m-2), F.E. (0.2 l m-2), F.E. (0.4 l m-2), B.E. (0.5 l m-2), B.E. (1.0 l m-2), Aq1 (0.33%), Aq1 (0.66%), Aq2 (200 gm m-2), Aq2 (250 gm m-2), and Control.
* The pooled, i.e. combined estimate of error is based on the assumption that error for (within) each treatment is the same (in the population).

Table 5.27: Statistical Analysis of the Melion spp. Oven-Dry Shoots and Roots.

ROW	C1	C2	C3	C4	C5	C6	C7	C8
1	0.1897	0.1193	0.1861	0.1742	0.1613	0.1670	0.1566	0.1346
2	0.1526	0.1339	0.1400	0.2131	0.1218	0.1475	0.1498	0.1827
3	0.1830	0.1496	0.1898	0.1850	0.1616	0.1150	0.1301	0.1714

ROW	C9	C10	C11	C12	C13	C14	C15	C16
1	0.1908	0.1347	0.1283	0.1921	0.1779	0.1598	0.1139	0.1229
2	0.2255	0.1468	0.1962	0.1497	0.1423	0.1769	0.1427	0.1173
3	0.1506	0.1412	0.1668	0.1733	0.1406	0.1369	0.1442	0.1255

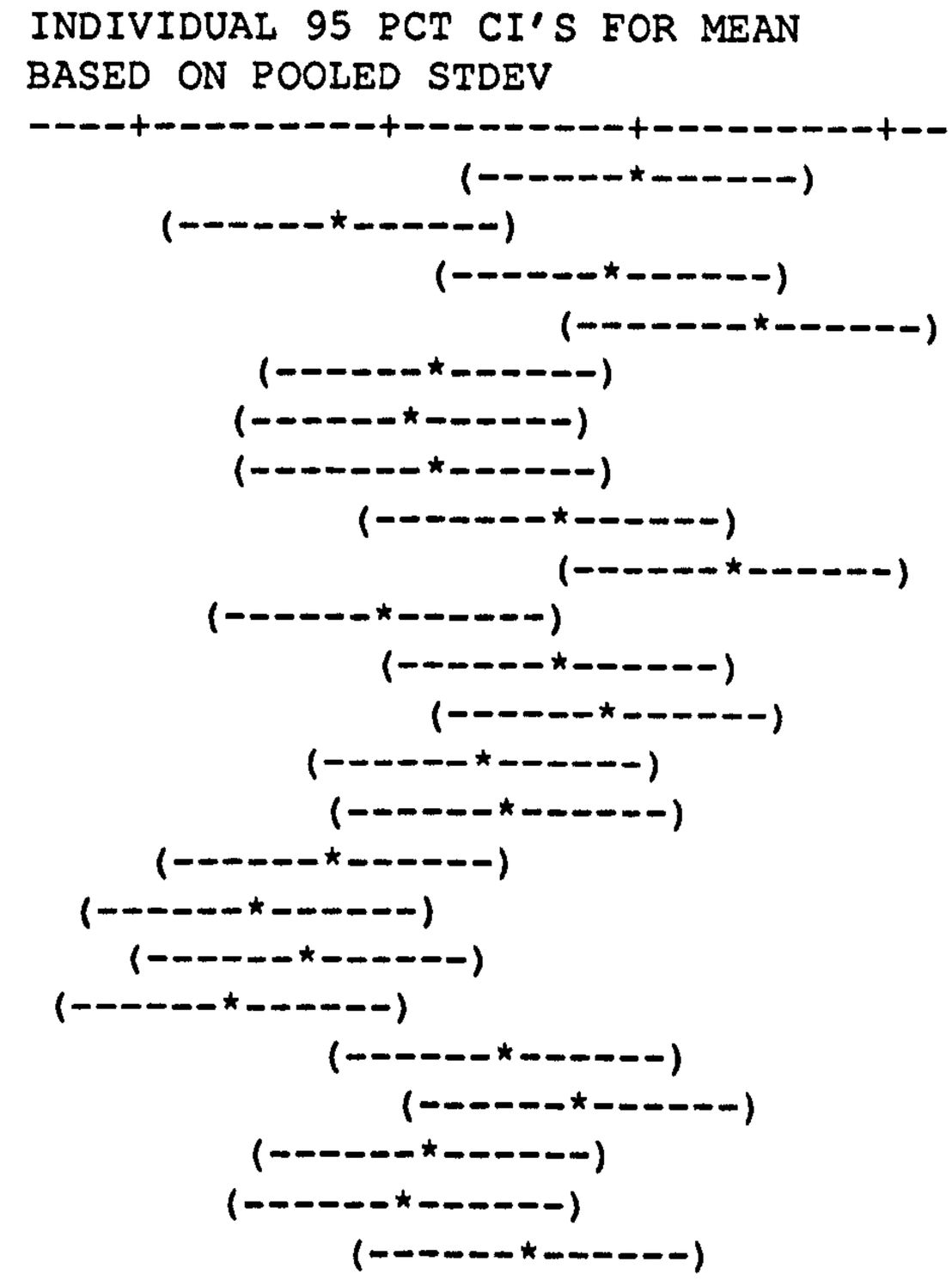
ROW	C17	C18	C19	C20	C21	C22	C23
1	0.1157	0.1083	0.1558	0.1561	0.1667	0.1216	0.1477
2	0.1256	0.1272	0.1907	0.1648	0.1276	0.1504	0.1630
3	0.1455	0.1181	0.1286	0.1870	0.1470	0.1572	0.1682

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	22	0.025362	0.001153	2.54
ERROR	46	0.020867	0.000454	
TOTAL	68	0.046229		

LEVEL	N	MEAN	STDEV
C1	3	0.17510	0.01977
C2	3	0.13427	0.01515
C3	3	0.17197	0.02775
C4	3	0.19077	0.02008
C5	3	0.14823	0.02289
C6	3	0.14317	0.02627
C7	3	0.14550	0.01376
C8	3	0.16290	0.02515
C9	3	0.18897	0.03748
C10	3	0.14090	0.00606
C11	3	0.16377	0.03405
C12	3	0.17170	0.02125
C13	3	0.15360	0.02106
C14	3	0.15787	0.02007
C15	3	0.13360	0.01708
C16	3	0.12190	0.00419
C17	3	0.12893	0.01518
C18	3	0.11787	0.00945
C19	3	0.15837	0.03113
C20	3	0.16930	0.01593
C21	3	0.14710	0.01955
C22	3	0.14307	0.01890
C23	3	0.15963	0.01066

POOLED STDEV = 0.02130



* C1-C23 are respectively, PVA1 (0.2%), PVA1 (0.4%), PVA2 (0.2%), PVA2 (0.4%), PEG3 (0.2%), PEG3 (0.4%), PEG4 (0.2%), PEG4 (0.4%), V1 (0.05 l m-2), V1 (0.10 l m-2), V2 (0.05 l m-2), V2 (0.10 l m-2), V3 (0.05 l m-2), V3 (0.10 l m-2), F.E. (0.2 l m-2), F.E. (0.4 l m-2), B.E. (0.5 l m-2), B.E. (1.0 l m-2), Aq1 (0.33%), Aq1 (0.66%), Aq2 (200 gm m-2), Aq2 (250 gm m-2), and Control.
* The pooled, i.e. combined estimate of error is based on the assumption that error for (within) each treatment is the same (in the population).

Table 5.28: Statistical Analysis of the Marram Grass Oven-Dry Shoots and Roots.

ROW	C1	C2	C3	C4	C5	C6	C7	C8
1	0.1536	0.1166	0.1576	0.1459	0.1706	0.1515	0.1960	0.1722
2	0.1501	0.1424	0.1821	0.1626	0.1611	0.1691	0.1482	0.2078
3	0.2006	0.1412	0.1607	0.1417	0.1379	0.1224	0.1784	0.1046

ROW	C9	C10	C11	C12	C13	C14	C15	C16
1	0.1578	0.1742	0.1908	0.1186	0.1388	0.1493	0.1268	0.0844
2	0.1976	0.1786	0.1777	0.1605	0.1751	0.1647	0.1338	0.1254
3	0.1679	0.1518	0.1858	0.1452	0.1759	0.1378	0.1468	0.0901

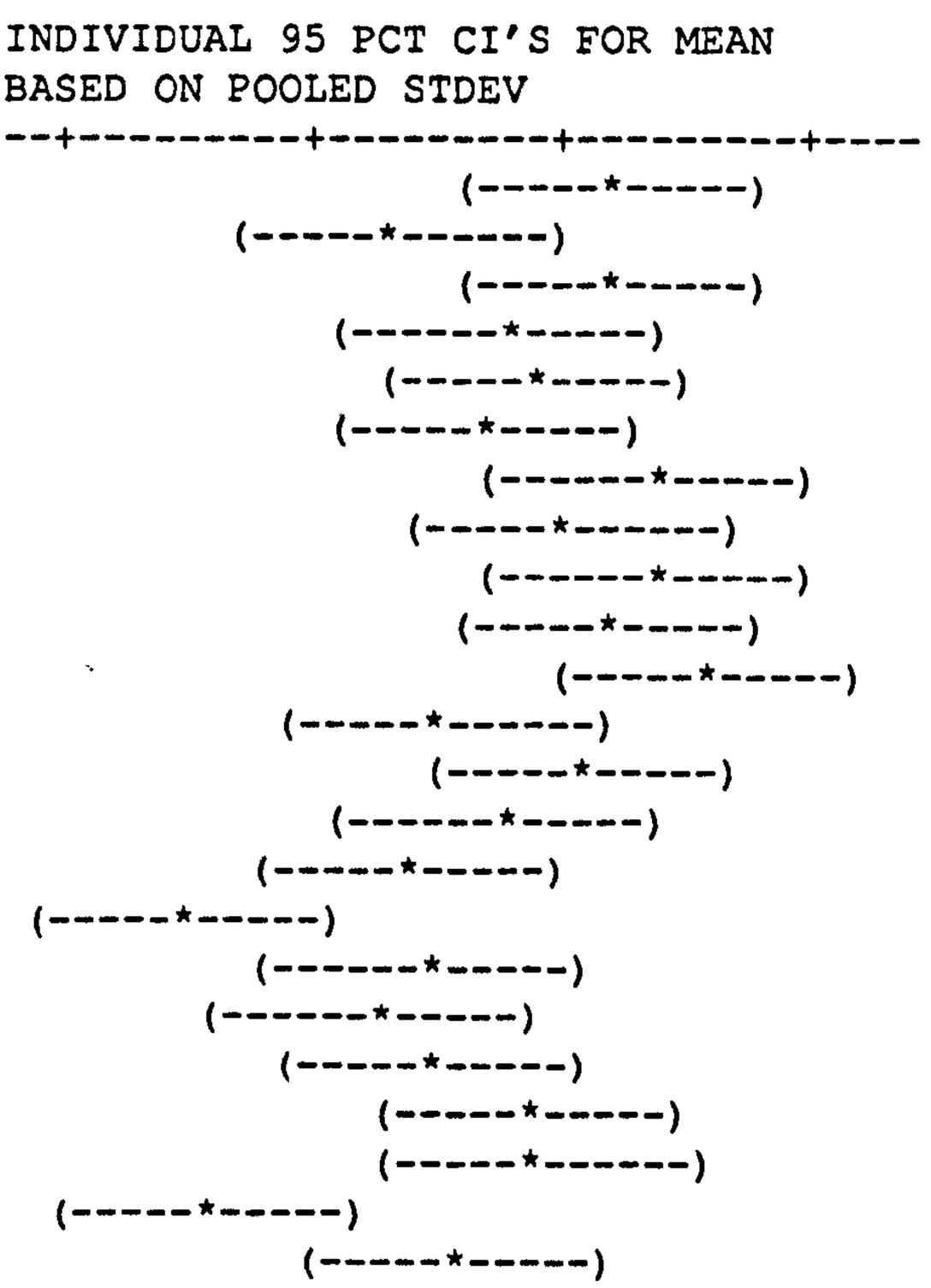
ROW	C17	C18	C19	C20	C21	C22	C23
1	0.1522	0.1409	0.1354	0.1783	0.1424	0.1162	0.1327
2	0.1104	0.1216	0.1640	0.1241	0.1669	0.1100	0.1567
3	0.1525	0.1281	0.1189	0.1675	0.1639	0.0844	0.1451

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	22	0.029017	0.001319	2.90
ERROR	46	0.020936	0.000455	
TOTAL	68	0.049953		

LEVEL	N	MEAN	STDEV
C1	3	0.16810	0.02820
C2	3	0.13340	0.01456
C3	3	0.16680	0.01334
C4	3	0.15007	0.01106
C5	3	0.15653	0.01682
C6	3	0.14767	0.02358
C7	3	0.17420	0.02418
C8	3	0.16153	0.05242
C9	3	0.17443	0.02069
C10	3	0.16820	0.01437
C11	3	0.18477	0.00661
C12	3	0.14143	0.02120
C13	3	0.16327	0.02119
C14	3	0.15060	0.01350
C15	3	0.13580	0.01015
C16	3	0.09997	0.02221
C17	3	0.13837	0.02422
C18	3	0.13020	0.00982
C19	3	0.13943	0.02282
C20	3	0.15663	0.02869
C21	3	0.15773	0.01336
C22	3	0.10353	0.01686
C23	3	0.14483	0.01200

POOLED STDEV = 0.02133



* C1-C23 are respectively, PVA1 (0.2%), PVA1 (0.4%), PVA2 (0.2%), PVA2 (0.4%), PEG3 (0.2%), PEG3 (0.4%), PEG4 (0.2%), PEG4 (0.4%), V1 (0.05 l m-2), V1 (0.10 l m-2), V2 (0.05 l m-2), V2 (0.10 l m-2), V3 (0.05 l m-2), V3 (0.10 l m-2), F.E. (0.2 l m-2), F.E. (0.4 l m-2), B.E. (0.5 l m-2), B.E. (1.0 l m-2), Aq1 (0.33%), Aq1 (0.66%), Aq2 (200 gm m-2), Aq2 (250 gm m-2), and Control.
* The pooled, i.e. combined estimate of error is based on the assumption that error for (within) each treatment is the same (in the population).

Table 5.29: Statistical Analysis for the Increases in the Eucalyptus spp. Heights (cm) (205 Days After Treatment).

ROW	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
1	16	22.0	41	28	17	19	17	30.5	40	27	32
2	9	33.5	33	26	39	13	32	24.5	16	30	9

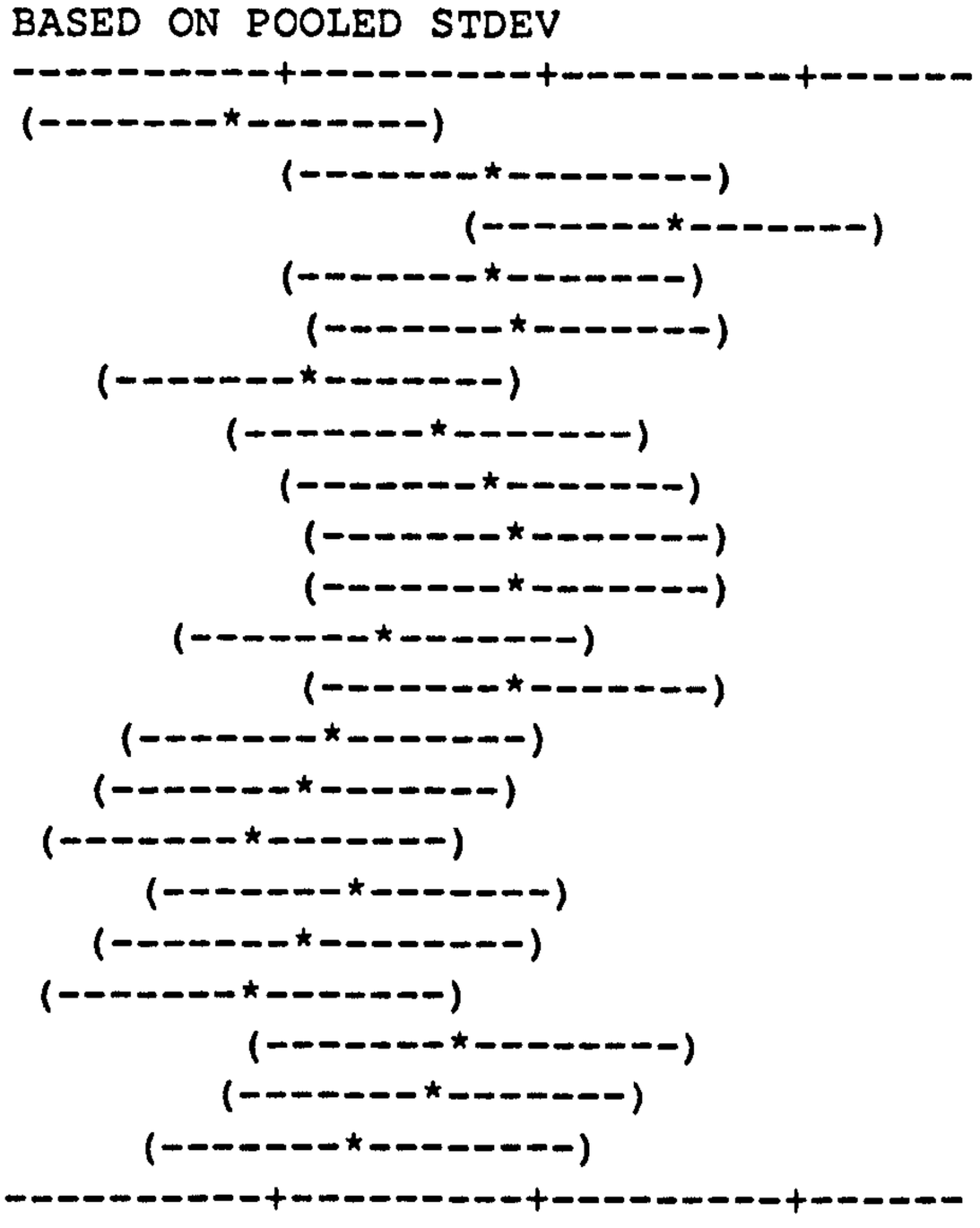
ROW	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21
1	29	21.0	8.5	16	25.5	15.5	8	22.5	21.5	19.0
2	27	14.5	24.5	12	13.5	19.0	18	30.0	26.5	21.5

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	20	1678.0	83.9	1.26
ERROR	21	1403.1	66.8	
TOTAL	41	3081.1		

LEVEL	N	MEAN	STDEV
C1	2	12.500	4.950
C2	2	27.750	8.132
C3	2	37.000	5.657
C4	2	27.000	1.414
C5	2	28.000	15.556
C6	2	16.000	4.243
C7	2	24.500	10.607
C8	2	27.500	4.243
C9	2	28.000	16.971
C10	2	28.500	2.121
C11	2	20.500	16.263
C12	2	28.000	1.414
C13	2	17.750	4.596
C14	2	16.500	11.314
C15	2	14.000	2.828
C16	2	19.500	8.485
C17	2	17.250	2.475
C18	2	13.000	7.071
C19	2	26.250	5.303
C20	2	24.000	3.536
C21	2	20.250	1.768

POOLED STDEV = 8.174



* C1-C21 are respectively, PVA1 (0.2%), PVA1 (0.4%), PVA2 (0.2%), PVA2 (0.4%), PEG3 (0.2%), PEG3 (0.4%), PEG4 (0.2%), PEG4 (0.4%), V1 (0.05 l m-2), V1 (0.10 l m-2), V2 (0.05 l m-2), V2 (0.10 l m-2), V3 (0.05 l m-2), V3 (0.10 l m-2), F.E. (0.2 l m-2), F.E. (0.4 l m-2), B.E. (0.5 l m-2), B.E. (1.0 l m-2), Aq1 (0.33%), Aq1 (0.66%), and Control.
* The pooled, i.e. combined estimate of error is based on the assumption that error for (within) each treatment is the same (in the population).

Table 6.1: Statistical Analysis of the Panicum spp. Germinations Number After 9 Days from Cultivation in Baiji Dunes Sand.

ROW	C1	C2	C3	C4	C5	C6	C7	C8	C9
1	0	2	1	1	4	1	3	3	3
2	3	3	2	0	0	4	6	4	3
3	2	0	1	1	2	1	2	2	1

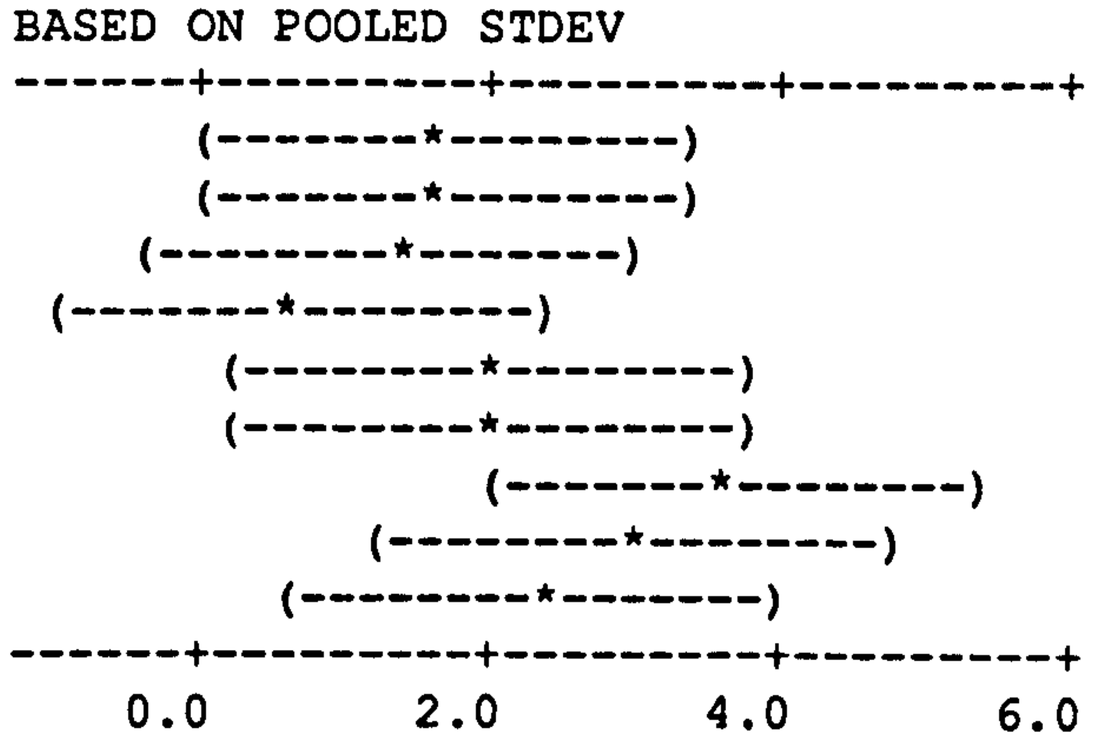
ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	8	18.96	2.37	1.12
ERROR	18	38.00	2.11	
TOTAL	26	56.96		

LEVEL	N	MEAN	STDEV
C1	3	1.667	1.528
C2	3	1.667	1.528
C3	3	1.333	0.577
C4	3	0.667	0.577
C5	3	2.000	2.000
C6	3	2.000	1.732
C7	3	3.667	2.082
C8	3	3.000	1.000
C9	3	2.333	1.155

POOLED STDEV = 1.453

INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV



* C1-C9 are respectively, PVA2 (0.2%), PVA2 (0.4%), F.E. (0.2 l m-2), F.E. (0.4 l m-2), B.E. (0.5 l m-2), B.E. (1.0 l m-2), Aq1 (0.33%), Aq1 (0.66%), and Control.
* The pooled, i.e. combined estimate of error is based on the assumption that error for (within) each treatment is the same (in the population).

Table 6.2: Statistical Analysis of the Merlinda spp. Germinations Number After 6 Days from Cultivation in Baiji Dunes Sand.

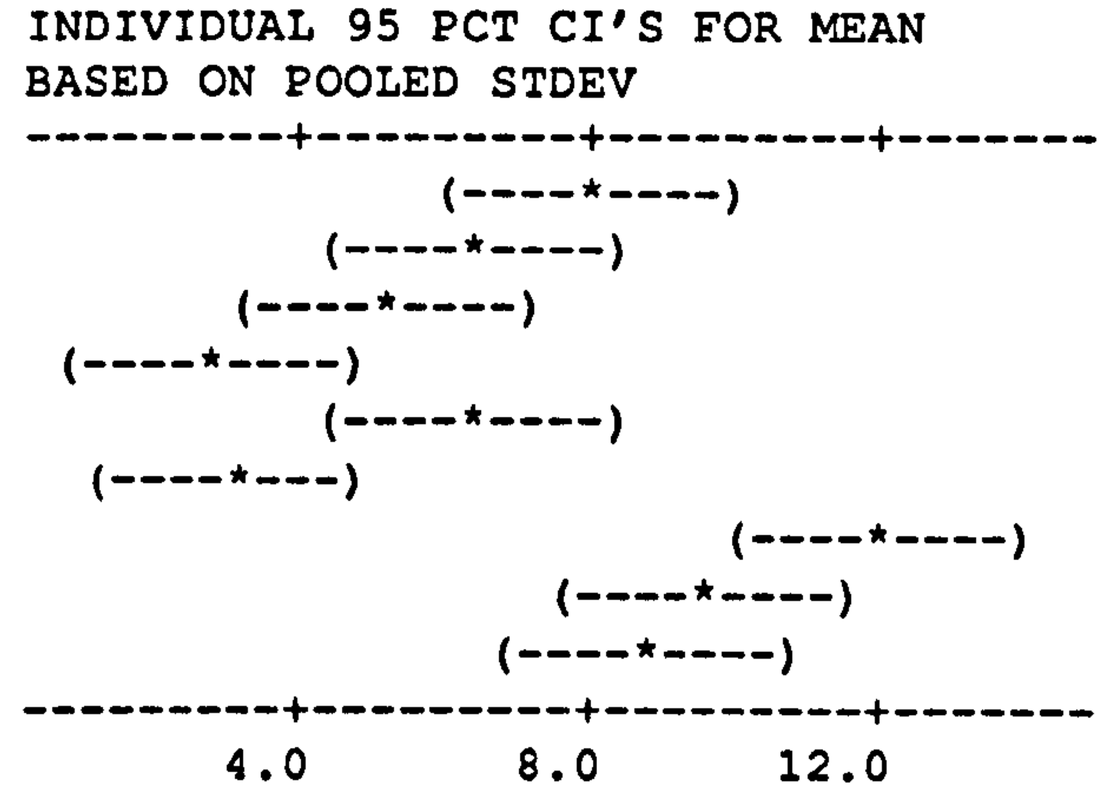
ROW	C1	C2	C3	C4	C5	C6	C7	C8	C9
1	10	7	7	2	7	2	14	8	10
2	8	8	5	4	7	3	10	12	8
3	6	4	4	2	5	4	12	9	8

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	8	222.67	27.83	10.44
ERROR	18	48.00	2.67	
TOTAL	26	270.67		

LEVEL	N	MEAN	STDEV
C1	3	8.000	2.000
C2	3	6.333	2.082
C3	3	5.333	1.528
C4	3	2.667	1.155
C5	3	6.333	1.155
C6	3	3.000	1.000
C7	3	12.000	2.000
C8	3	9.667	2.082
C9	3	8.667	1.155

POOLED STDEV = 1.633



* C1-C9 are respectively, PVA2 (0.2%), PVA2 (0.4%), F.E. (0.2 l m-2), F.E. (0.4 l m-2), B.E. (0.5 l m-2), B.E. (1.0 l m-2), Aql (0.33%), Aql (0.66%), and Control.
* The pooled, i.e. combined estimate of error is based on the assumption that error for (within) each treatment is the same (in the population).

Table 6.3: Statistical Analysis of the Melion spp. Germinations Number After 6 Days from Cultivation in Baiji Dunes Sand.

ROW	C1	C2	C3	C4	C5	C6	C7	C8	C9
1	14	7	4	6	4	4	21	12	8
2	10	7	5	3	7	4	17	15	6
3	12	6	7	3	2	4	17	10	10

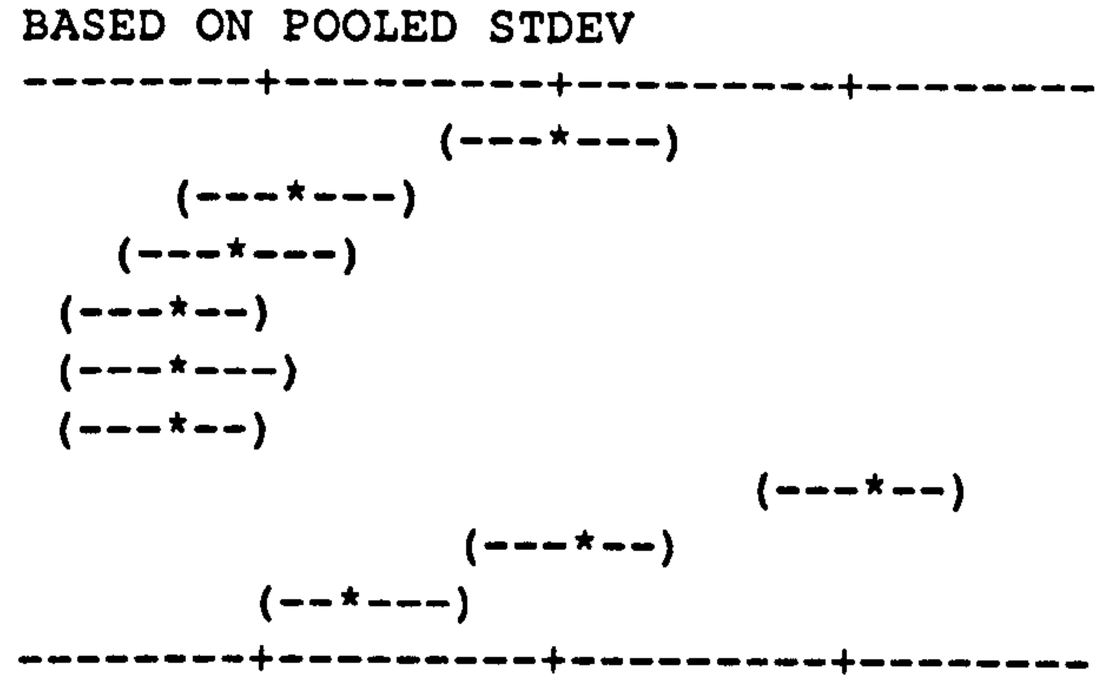
ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	8	584.67	73.08	20.77
ERROR	18	63.33	3.52	
TOTAL	26	648.00		

LEVEL	N	MEAN	STDEV
C1	3	12.000	2.000
C2	3	6.667	0.577
C3	3	5.333	1.528
C4	3	4.000	1.732
C5	3	4.333	2.517
C6	3	4.000	0.000
C7	3	18.333	2.309
C8	3	12.333	2.517
C9	3	8.000	2.000

POOLED STDEV = 1.876

INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV



* C1-C9 are respectively, PVA2 (0.2%), PVA2 (0.4%), F.E. (0.2 l m-2), F.E. (0.4 l m-2), B.E. (0.5 l m-2), B.E. (1.0 l m-2), Aql (0.33%), Aql (0.66%), and Control.
* The pooled, i.e. combined estimate of error is based on the assumption that error for (within) each treatment is the same (in the population).

Table 6.4: Statistical Analysis of the Marram Grass Germinations Number After 9 Days from Cultivation in Baiji Dunes Sand.

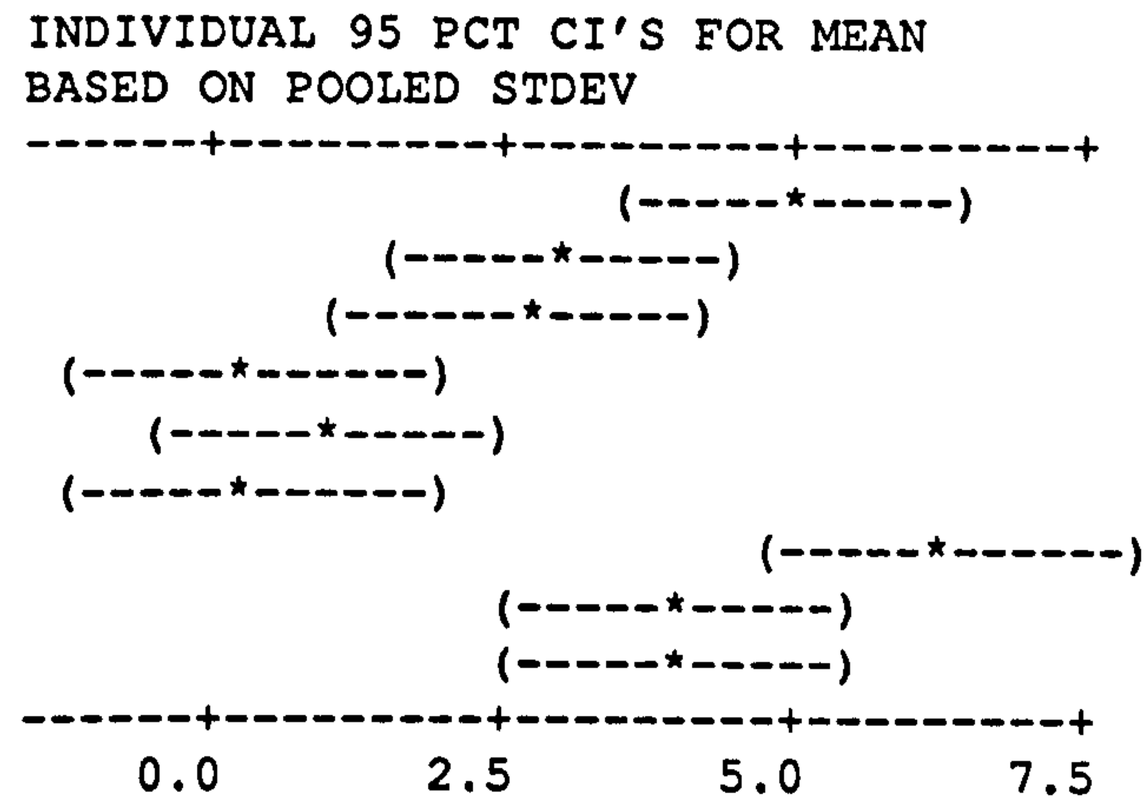
ROW	C1	C2	C3	C4	C5	C6	C7	C8	C9
1	6	3	2	0	2	1	8	6	5
2	4	2	2	1	0	0	5	1	4
3	5	4	4	0	1	0	6	5	3

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	8	106.30	13.29	7.80
ERROR	18	30.67	1.70	
TOTAL	26	136.96		

LEVEL	N	MEAN	STDEV
C1	3	5.000	1.000
C2	3	3.000	1.000
C3	3	2.667	1.155
C4	3	0.333	0.577
C5	3	1.000	1.000
C6	3	0.333	0.577
C7	3	6.333	1.528
C8	3	4.000	2.646
C9	3	4.000	1.000

POOLED STDEV = 1.305



* C1-C9 are respectively, PVA2 (0.2%), PVA2 (0.4%), F.E. (0.2 l m-2), F.E. (0.4 l m-2), B.E. (0.5 l m-2), B.E. (1.0 l m-2), Aq1 (0.33%), Aq1 (0.66%), and Control.
* The pooled, i.e. combined estimate of error is based on the assumption that error for (within) each treatment is the same (in the population).

(Appendix 3)

Table 8.1: Sand Accumulation (A) and Sand Erosion (E) in (mm) for Druridge Bay Field Site 1.

Date: 5th Jan. 1989

10	2	5	2	0	3	0	5	7	2	4	6	8	12
(E)	(E)	(A)	(A)	(E)	(A)	(E)	(A)	(A)	(A)	(A)	(A)	(A)	(A)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
7	10	0	5	4	0	0	0	5	0	2	0	6	8
(E)	(E)	(E)	(A)	(A)	(E)	(E)	(E)	(A)	(E)	(A)	(E)	(A)	(A)

7 3 5 6 2 1 4

0	2	6	3	3	3	2	3	5	2	4	0	3	2
(E)	(A)	(E)	(E)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(E)	(A)	(A)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	6	10	5	5	6	2	0	0	4	0	0	5	0
(A)	(A)	(E)	(A)	(A)	(A)	(A)	(E)	(E)	(A)	(E)	(E)	(A)	(E)

1 7 3 2 6 4 5

0	0	2	0	5	0	2	4	5	2	0	2	6	7
(E)	(E)	(A)	(E)	(A)	(E)	(A)	(A)	(A)	(A)	(E)	(A)	(A)	(E)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
4	3	2	5	0	4	2	0	2	5	4	4	8	10
(A)	(A)	(A)	(A)	(E)	(A)	(A)	(E)	(A)	(A)	(A)	(A)	(E)	(E)

5 3 2 1 4 6 7

Table 8.2: Sand Accumulation (A) and Sand Erosion (E) in (mm) for Druridge Bay Field Site 1.

Date: 7th Feb. 1989

480	440	450	443	427	442	418	464	504	472	534	560	524	516
(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
490	460	430	450	438	445	476	483	512	493	539	555	548	540
(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)
7		3		5		6		2		1		4	

486	490	469	482	476	484	512	498	502	510	538	544	540	548
(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
478	484	476	470	480	482	476	488	503	512	524	550	546	560
(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)
1		7		3		2		6		4		5	

470	488	505	490	494	487	469	484	492	498	516	522	530	526
(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
490	482	512	503	507	496	490	493	498	508	514	520	510	540
(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)
5		3		2		1		4		6		7	

Table 8.3: Sand Accumulation (A) and Sand Erosion (E) in (mm) for Druridge Bay Field Site 1.

Date: 7th Mar. 1989

20	10	2	0	30	2	4	0	0	3	10	15	45	35
(E)	(A)	(A)	(E)	(A)	(A)	(A)	(E)	(E)	(A)	(E)	(E)	(E)	(E)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
42	10	5	18	25	45	32	2	5	5	45	45	70	55
(E)	(E)	(A)	(E)	(A)	(A)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)

7 3 5 6 2 1 4

8	0	10	25	50	50	48	50	35	40	2	20	52	50
(E)	(E)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(E)	(E)	(E)	(E)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
67	30	3	2	40	30	52	48	52	50	0	45	90	100
(E)	(E)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(E)	(E)	(E)	(E)

1 7 3 2 6 4 5

2	0	10	0	20	25	12	4	4	25	50	45	65	110
(E)	(E)	(E)	(E)	(A)	(A)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
25	10	30	10	0	12	60	55	12	90	140	55	130	190
(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)

5 3 2 1 4 6 7

Table 8.4: Sand Accumulation (A) and Sand Erosion (E) in (mm) for Druridge Bay Field Site 1.

Date: 28 Mar. 1989

0	0	0	0	0	0	0	0	0	0	0	0	0	0
(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
0	0	0	0	0	5	0	0	0	0	0	0	5	5
(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)

7 3 5 6 2 1 4

20	0	0	0	0	0	5	0	0	0	7	7	30	30
(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
0	20	15	10	5	5	0	0	0	0	5	5	0	30
(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)

1 7 3 2 6 4 5

10	15	15	15	10	10	0	0	0	0	0	15	80	105
(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
15	15	15	15	15	0	0	15	0	0	30	0	190	190
(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)

5 3 2 1 4 6 7

Table 8.5: Sand Accumulation (A) and Sand Erosion (E) in (mm) for Druridge Bay Field Site 1.

Date: 20th Apr. 1989

55	60	40	110	110	70	100	160	160	150	135	140	100	75
(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
60	45	75	70	100	65	120	160	140	130	140	140	90	15
(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(E)

7 3 5 6 2 1 4

175	60	40	40	35	55	90	87	120	90	70	45	5	130
(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(E)	(E)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
120	155	75	75	55	80	75	95	95	90	75	50	0	120
(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(E)	(E)

1 7 3 2 6 4 5

80	45	60	95	90	80	70	70	50	10	0	23	45	245
(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(E)	(E)	(E)	(E)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
160	130	115	110	105	90	65	100	15	20	20	20	25	20
(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(E)	(E)	(E)	(E)

5 3 2 1 4 6 7

Table 8.6: Sand Accumulation (A) and Sand Erosion (E) in (mm) for Druridge Bay Field Site 1.

Date: 4th May 1989

10	0	0	0	0	0	10	10	0	20	15	25	30	30
(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	5	0	0	0	0	0	15	5	35	20	15	10	10
(E)	(A)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)

7 3 5 6 2 1 4

0	0	5	0	0	0	0	0	0	0	0	0	10	25
(E)	(E)	(A)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	50	0	0	15	15	20	20	10	0	0	5	0	15
(A)	(E)	(E)	(E)	(A)	(A)	(A)	(A)	(A)	(E)	(E)	(E)	(E)	(E)

1 7 3 2 6 4 5

30	30	10	0	0	0	0	0	0	0	0	5	0	0
(A)	(A)	(A)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(A)	(E)	(E)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
0	0	0	0	0	0	7	0	0	0	5	0	5	10
(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(A)	(E)	(E)	(E)

5 3 2 1 4 6 7

Table 8.7: Sand Accumulation (A) and Sand Erosion (E) in (mm) for Druridge Bay Field Site 1.

Date: 20th Jun. 1989

0	2	2	0	2	0	15	0	20	0	45	8	0	50
(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	10	0	0	15	25	15	15	10	0	2	2	10	40
(E)	(E)	(E)	(E)	(A)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)

7 3 5 6 2 1 4

0	0	0	0	0	0	30	0	0	0	5	5	0	120
(E)	(E)	(E)	(E)	(E)	(E)	(A)	(E)	(E)	(E)	(E)	(E)	(E)	(E)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
5	5	25	0	0	5	5	5	0	0	0	10	15	87
(A)	(A)	(A)	(E)	(E)	(A)	(A)	(E)	(E)	(E)	(E)	(E)	(E)	(E)

1 7 3 2 6 4 5

20	20	10	0	0	0	4	6	0	40	0	0	100	120
(A)	(A)	(A)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
15	0	25	0	0	0	0	15	40	40	25	5	100	120
(A)	(E)	(A)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(A)	(E)	(E)

5 3 2 1 4 6 7

Table 8.8: Sand Accumulation (A) and Sand Erosion (E) in (mm) for Druridge Bay Field Site 1.

Date: 20th Sep. 1989

10	0	5	5	25	25	0	0	30	10	5	40	80	200
(E)	(E)	(A)	(A)	(A)	(A)	(E)	(E)	(A)	(E)	(E)	(E)	(E)	(E)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
30	3	0	15	15	5	5	5	30	25	65	80	120	200
(E)	(E)	(E)	(A)	(A)	(A)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)

7 3 5 6 2 1 4

50	30	5	15	0	5	0	0	5	5	0	0	30	200
(A)	(A)	(A)	(A)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	15	15	3	5	5	5	3	0	0	7	90	50	200
(E)	(A)	(E)	(E)	(A)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)

1 7 3 2 6 4 5

30	10	30	2	0	0	2	0	0	0	0	0	180	200
(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)
—	—	—	—	—	—	—	—	—	—	—	—	—	—
90	85	80	80	30	0	30	0	0	0	0	0	180	200
(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)	(E)

5 3 2 1 4 6 7